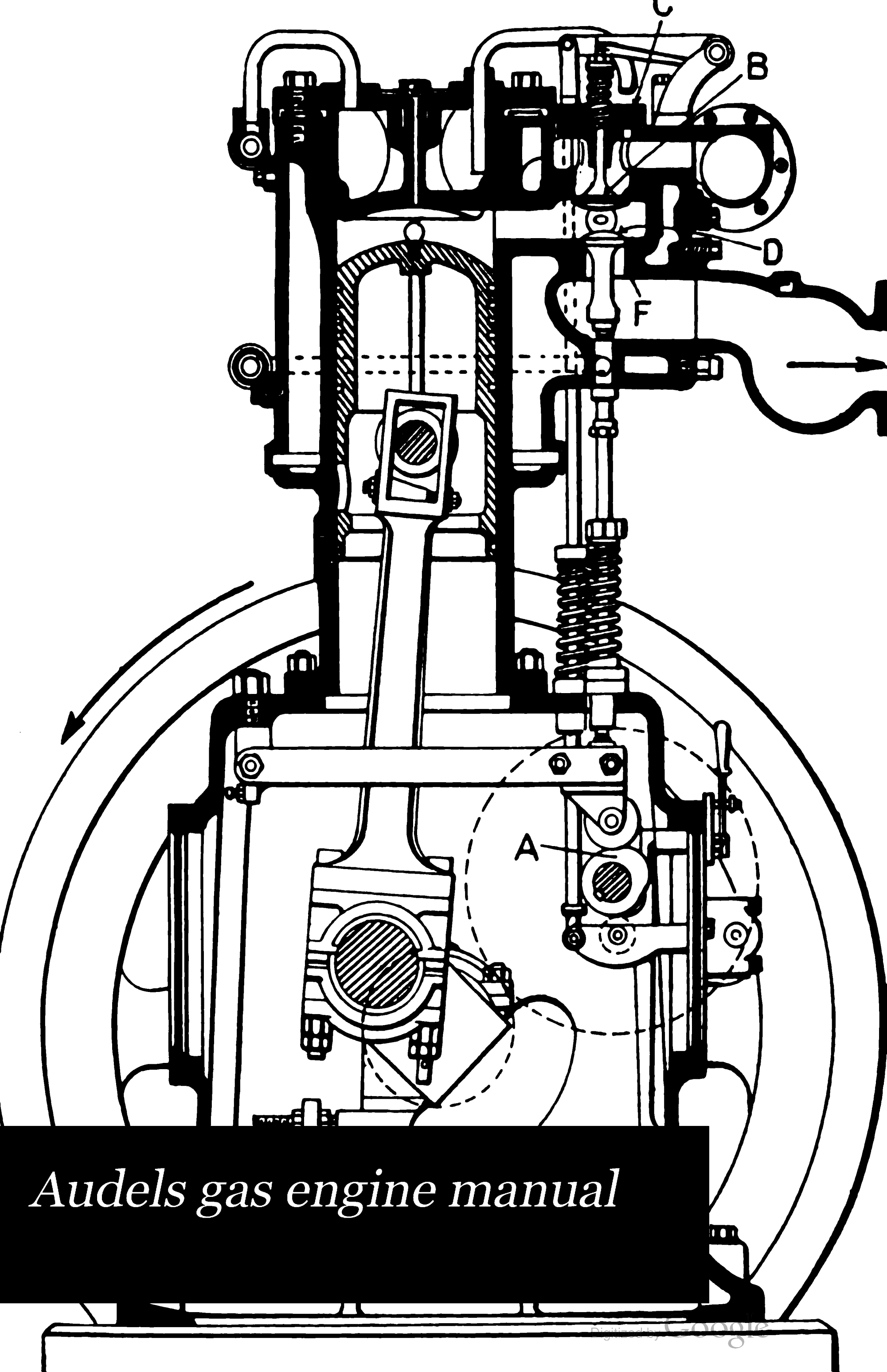

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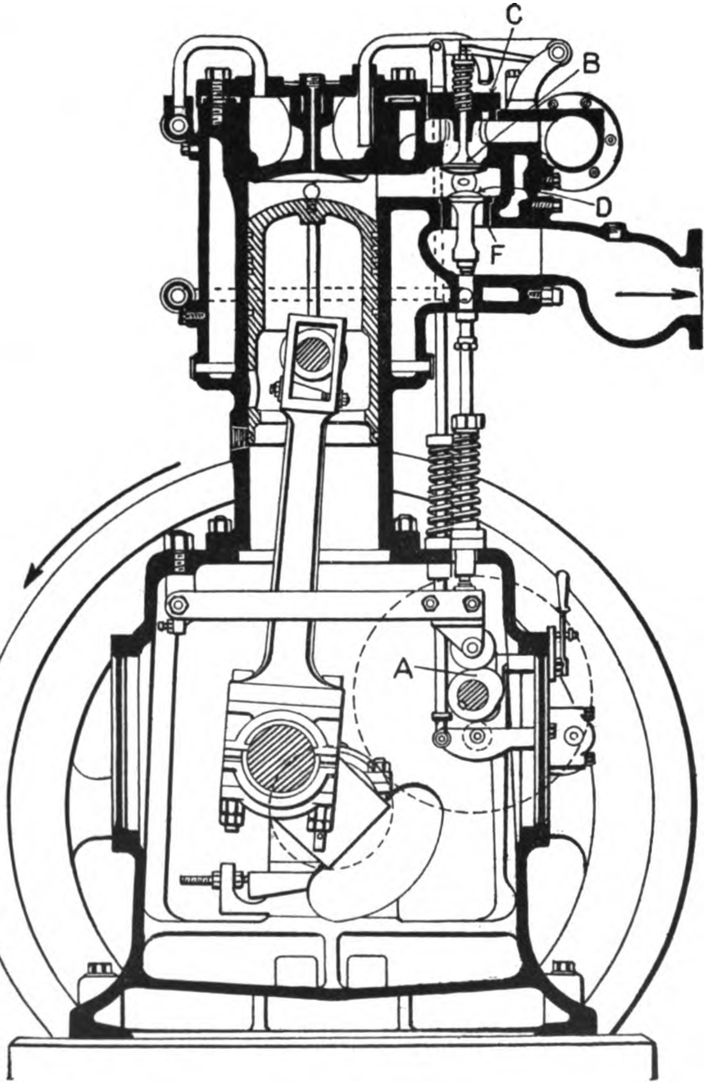

See Paragraph Two Hundred and Six.

AUDELS

GAS ENGINE MANUAL

A PRACTICAL TREATISE

RELATING TO THE

THEORY AND MANAGEMENT OF GAS, GASOLINE AND OIL ENGINES. INCLUDING CHAPTERS ON PRODUCER GAS PLANTS, MARINE MOTORS AND AUTOMOBILE ENGINES

ILLUSTRATED

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INTRODUCTION.

A complete study of the gas engine problem would involve consideration of the two general classes of motors operated by the expansive energy of combustible gases, namely—piston engines with reciprocating action, and turbine engines with rotary motion.

Conditions relating to the latter, however, are in such an experimental stage, that very little of practical interest can be stated about them at the present time.

On the other hand, the various types of piston engine have been developed to a stage of high efficiency, and, therefore, will be exclusively considered in this work, with occasional references to the other type for the purpose of comparative illustration.

The gas engine belongs to the general class of motors which convert natural energy existing in the form of heat into mechanical energy, which is subsequently utilized for the performance of useful work.

These motors are usually called heat engines, and may be divided into two general classes, according to the manner in which the heat is applied to the working substance of the engine, as follows:

1. External combustion engines, driven by the expansive energy of steam or air heated from an external source through the walls of the vessel containing the working substance, such as the various types of steam and hot air engines.

2. The internal combustion engine driven by the expansive energy of air heated by the combustion of the fuel with which it is intimately mixed, and which is burned within the working cylinder of the engine.

All types of gas, gasoline, and oil engines belong to the second class, their principal distinguishing feature being the direct method of heating employed, a method which may be conveniently called the *gas engine method.*

If the study of the gas engine were confined merely to its action as an internal combustion engine, very little needs to be added to the exhaustive considerations of Carnot, Rankine and others, relative to the action of the ideal heat engine, for practically all of the advantages due to the method of direct heating may be obtained by the application of superheating methods to the external combustion engine.

But, the application of the gas engine method signifies something more than the mere transference of the furnace from the boiler to the interior of the working cylinder. The use of fuel in a gaseous form intimately mixed with the working substance, makes the cycle of action of the working substance independent of the cycle of action of the mechanism of the engine, and permits the use of a great variety of fuels, and many different mechanical arrangements. Furthermore, the temperature and the pressure of the working substance become independent of each other, thus permitting the attainment of initial temperatures much higher than those possible in any other class of heat engines, with a consequent increase of thermal efficiency without a corresponding increase of the load on the piston.

As the method of heating distinguishes the gas engine from other classes of heat engine, similarly, the conditions of tem-

perature, volume, and pressure, of the working substance which obtain at heating, serve to distinguish the various types of gas engine when considered according to the cycles of action of their working substances.

By maintaining one of these conditions constant and permitting variations of the other two, three important cycles of the working substance may be obtained as follows:

1. By heating at constant temperature, with increase of volume and decrease of pressure, and *vice versa.*

2. By heating at constant pressure, with increase of volume and increase of temperature.

3. By heating at constant volume, with increase of temperature and increase of pressure.

The first method is that of a steam engine using saturated steam, and is most nearly approached by the cycle of the Diesel gas or oil engine.

The second method is that of a steam engine using superheated steam, and is represented among the gas engines by the cycle of the Brayton engine. It is the method most suitable in connection with the development of the gas turbine.

The third method is that of the most successful application of the gas engine method, and is represented by the cycle of the Otto engine.

These cycles, acting in connection with a great variety of permissible engine cycles, introduce several other modes of expansion and compression of the working substance in addition to the adiabatic and isothermal methods which conform to Mariotte's law for gases. The chief of these are the isometric and the isopiestic, which permit of the use of various engine cycles

according to the character of the fuel used or the conditions of service required, and which call for a combination of the Mariotte and Gay-Lussac laws for the complete analysis of the two inter-related cycles of a gas engine operating under actual working conditions.

In the following chapters, the theory and practice of the gas engine and allied types of piston motor, will be considered as principally operating under the third cycle, or heating at constant volume, with a view to the establishment of a clear understanding of the exact relation of the factor of compression, introduced by the second and third cycles, to both the thermal and mechanical efficiency of a gas engine, a relation which makes it an essential condition in the successful operation of all classes of internal combustion motor.

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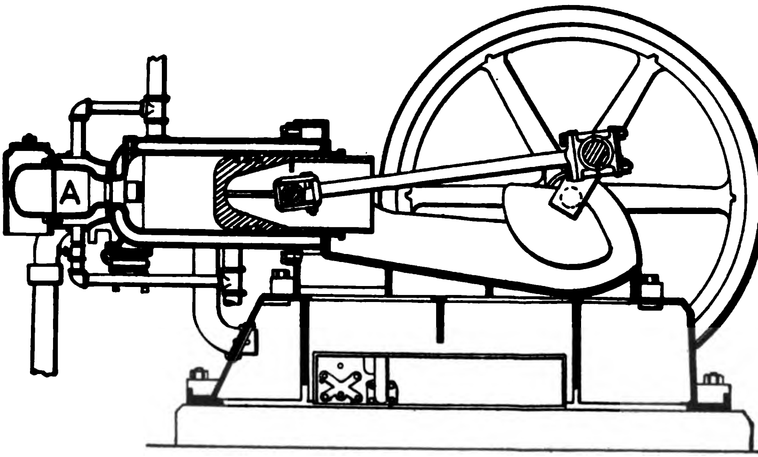
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CHAPTER I.

HISTORICAL DEVELOPMENT.

1. **The Abbé d' Hautefeuille Engine.** The prototype of the modern internal combustion engine was first conceived in 1678, by the Abbé d' Hautefeuille, an eminent mineralogist and chemist of France. He proposed to use the explosive energy of gunpowder to drive a piston in a cylinder; but it does not appear that any machine was actually built by him or under his direction, and besides the fact that about two years later similar machines employing the same motive power were devised by Christian Huygens and Denis Papin, no further development of this class of engines appears to have been attempted until 1791.

2. **The Barber Engine.** In 1791, John Barber, an Englishman, patented an engine in which a mixture of hydrocarbon gas and air was used for the charge. This machine was essentially a *gas turbine.* The gas used was generated from solid or liquid fuel, and after being mixed with a suitable quantity of air and water, was exploded in a vessel called the exploder, from which the developed energy was exerted against the vanes of a turbine.

3. **The Street Patents.** A few years later, John Street, also an Englishman, was granted a patent for an engine which he proposed to operate by the use of vapor derived from a liquid fuel and air, which was to be ignited by a flame and exploded in a suitable cylinder.

4. **The Lebon Engine.** About the year 1799, Philip Lebon, a Frenchman, patented an engine designed to use coal gas for the fuel component of the charge, and was followed soon afterwards by several inventors whose machines, although of very ingenious construction, do not appear to have attained any practical success.

5. **The Lenoir Engine.** In 1860, Lenoir, a Frenchman, produced the *first practical gas engine*—a one horse-power machine

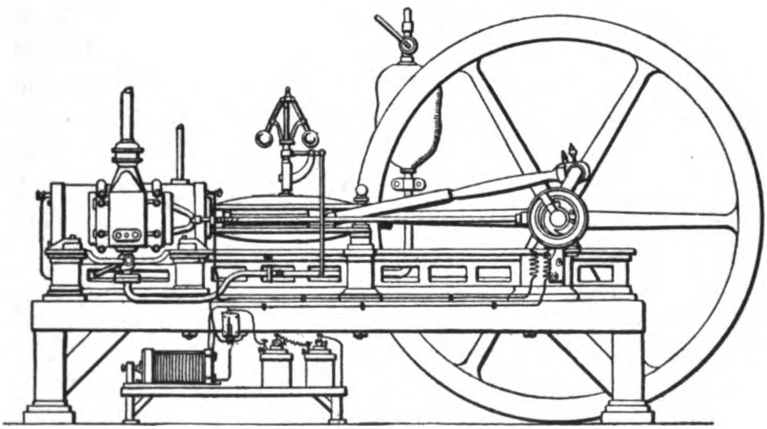

Fig. 1—Lenoir Engine (1860)
(Paragraph 5)

of the double acting type, equipped with a cylinder 3 inches in diameter, in which a piston worked with a 5½ inch stroke. In this engine, the charge composed of an explosive mixture of gas and air, was drawn into the cylinder during the first half of the forward stroke of the piston and exploded by an electric spark from a Ruhmkorff coil at the beginning of the second half of the stroke. The burnt gas was expelled during the return stroke at the same time that effective work was being done by

the explosion on the other side of the piston. The igniter was placed in the cylinder wall at a point opposite the half length of the stroke, so that the platinum igniter points protruded into the cylinder. The electric spark that jumped continually between them was exposed to the gas in each end of the cylinder, alternately, by the forward and backward movements of the piston. The cylinder was provided with a water jacket for preventing the overheating of its walls, and the engine worked so smoothly and regularly that it inspired the belief that it would prove a successful substitute for the steam engine.

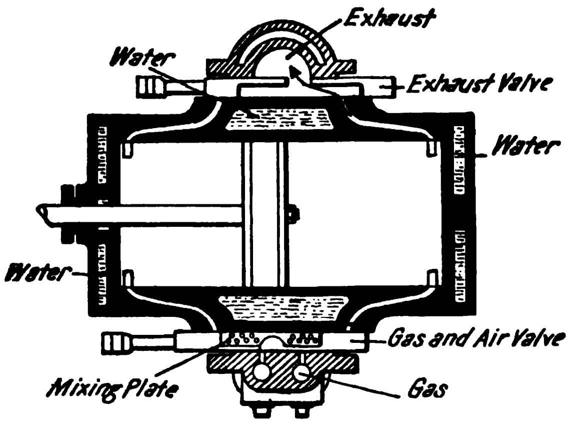

Fig. 2.—Lenoir Engine Cylinder, (Paragraph 5)

So much so, that several prominent firms began manufacturing them in sizes up to 12 horse-power; but many defects were soon discovered, especially the enormous expense for fuel due to the consumption of over 100 cubic feet of illuminating gas per brake horse-power under the most favorable load, and their manufacture was soon discontinued. *Fig.* 1, shows a general view, and *Fig.* 2, a cross-section of the cylinder.

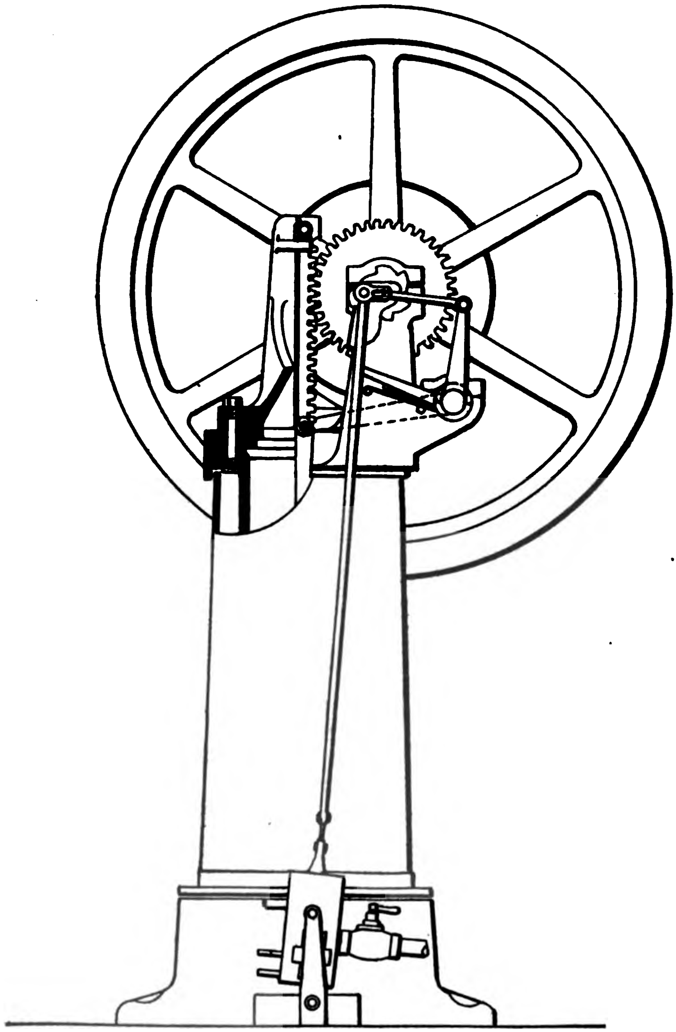

Fig. 3.—Otto-Langen Atmospheric Engine (1862)

(Paragraph 7)

6. The Beau de Rochas Patents. Some good was accomplished, however, by the effort directed towards the manufacture of the Lenoir machine. The attention of inventors and scientists, so long directed towards the development of the steam engine, was redirected to the gas engine, and led to the important experiments and works of Beau de Rochas, N. A. Otto, and Eugene Langen, during the period 1861 to 1878. In 1862, Rochas patented the specifications for an engine in which the charge passed through four distinct phases in one cycle of operations, briefly described as follows: The charge was drawn into the cylinder during the first forward stroke of the piston, compressed during the return stroke, ignited and exploded at the beginning of the second forward stroke, and the burnt gases expelled by the second return stroke. These specifications defined an engine far superior to any of the machines produced up to that time, but although he was on the very threshold of success, Rochas failed to build an engine under his patents, and they remained practically unnoticed for sixteen years.

7. The Otto-Langen Atmospheric Engine. About the same time (1862) Otto, then a young German merchant, built an experimental engine on a somewhat similar principle, but abandoned it for want of success. Subsequently, in 1867, with the assistance of Eugene Langen, he produced a vertical engine in which a "free piston" was driven upwards by the explosion of the charge in the cylinder, giving working power only on the downward stroke under the pressure of the atmosphere. Although crude in construction, it consumed only about one-half the amount of gas required by the Lenoir engine, and not only demonstrated the advantage of compression, but was the *first atmospheric engine to attain any commercial importance, for it came into somewhat extensive use notwithstanding its defects. Fig.* 3, shows a side elevation of the engine.

8. The Brayton Engine. About the year 1873, Brayton, of Philadelphia, produced the *first successful gas engine proper built in the United States.* It was of the vertical type and con-

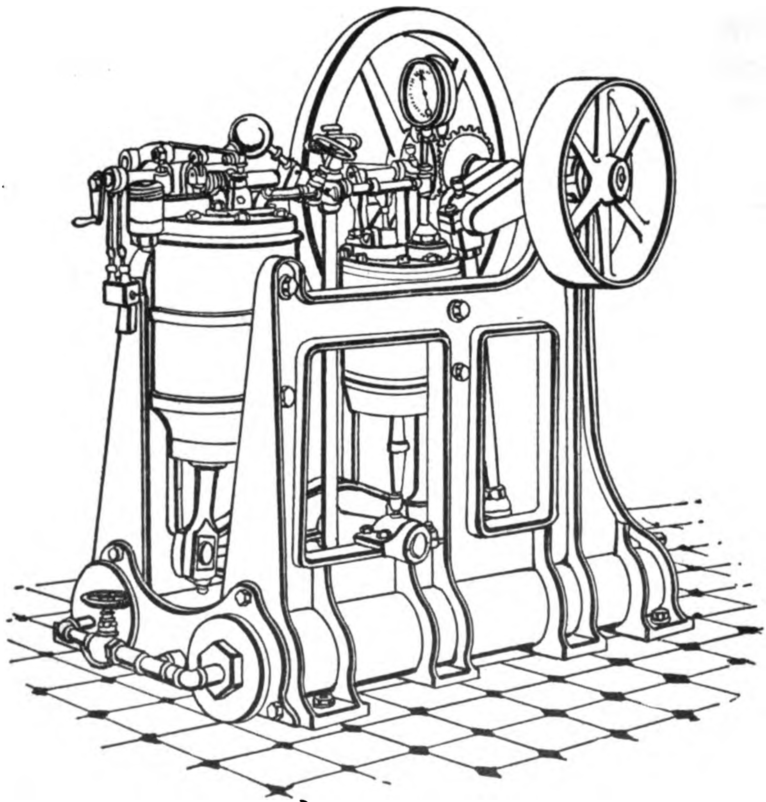

Fig. 4.—Brayton Engine (1873)
(Paragraph 8)

sisted of a working cylinder and a separate charging cylinder. The charge used was an explosive mixture of gas and air in the proportion of 1 of gas to 9 of air, which was compressed in the

charging cylinder under a pressure of 74 pounds to the square inch and then admitted to the working cylinder during the earlier part of the downward stroke of the piston. The charge thus introduced was ignited after the piston had passed one-fourth of its stroke, the force of the explosion pushing it to the completion of the stroke without any increase in pressure. Accidental ignition of the highly inflammable compressed mixture

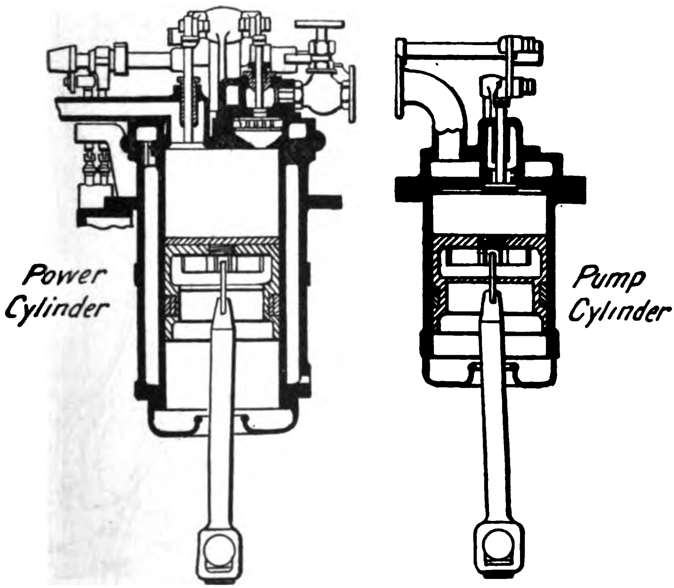

Fig. 5.—BRAYTON ENGINE, cross sections through cylinders. (Paragraph 8.)

in the charging cylinder was prevented by placing several layers of wire gauze in the port connecting the charging cylinder with the working cylinder. On test, the engine showed a thermal efficiency about 33 per cent. higher than that of the Lenoir engine. *Fig.* 4, shows a general view of the engine, and *Fig.* 5, vertical cross-sections through the cylinders.

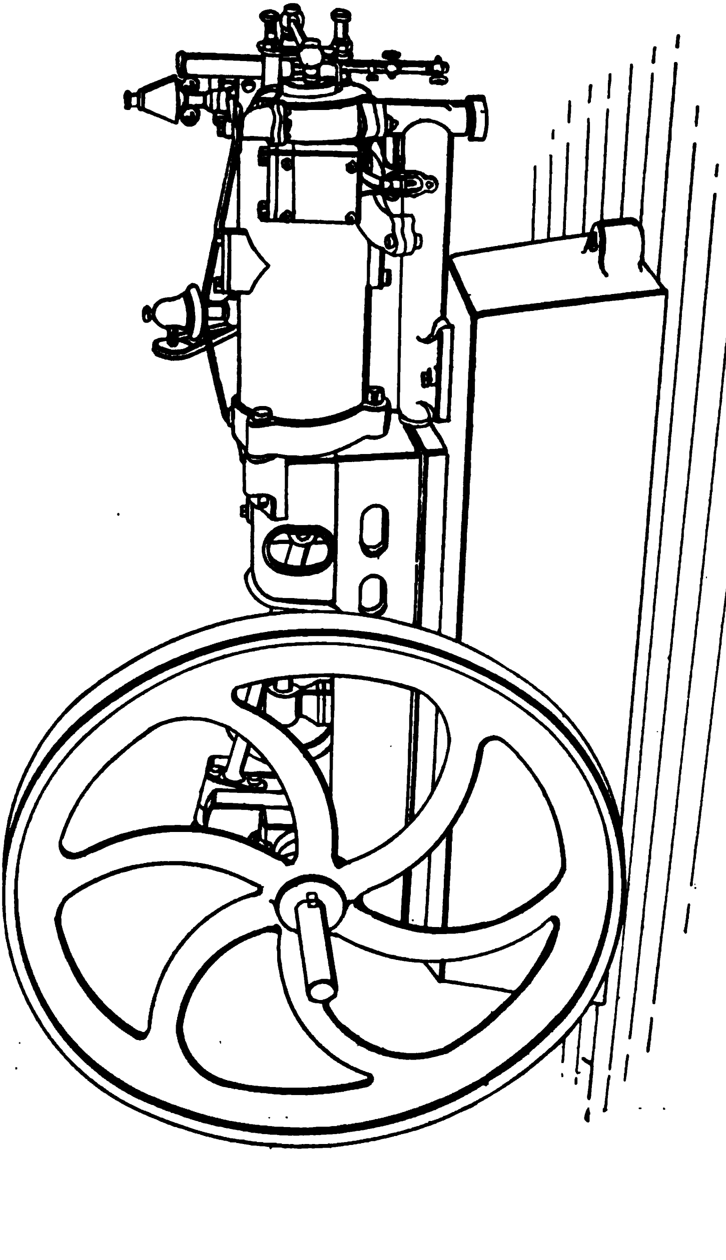

Fig. 8.—Otto Four-Cycle Engine (Paris Exposition 1878.) (Paragraph 9.)

9. **The Otto Four-Cycle Engine.** Otto's labors did not cease with the production of his atmospheric engine in 1867.

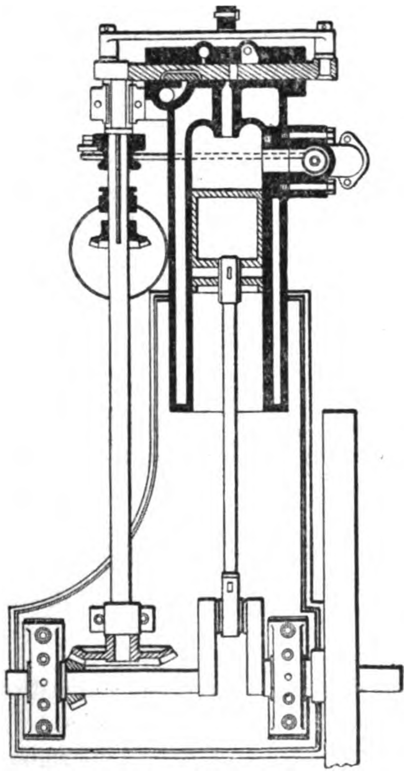

Fig. 7.—Otto Four-Cycle Engine (Paragraph 9.)

At the Paris Exposition of 1878, he exhibited a new engine in which he had practically applied the Rochas cycle of operations. Its most ingenious feature was a slide valve which accomplished the double purpose of admitting the charge to the working cylinder and then igniting it by means of a gas flame which passed from the jet in the valve cover, through the valve itself, into the combustion chamber. It worked *noiselessly, smoothly,*

and regularly. Its fuel economy was equal to that of his atmospheric engine of 1867, and its thermal efficiency was much higher than that of the Brayton engine. It appeared to clearly establish the fact, that the *four-part cycle was the most effective method* for overcoming the many difficulties which, up to that time, had prevented the successful operation of internal combustion engines, and *opened a new chapter* in the history of their development. *Fig.* 6, shows a general view of the engine, and *Fig.* 7, a sectional plan through the cylinder.

In Dugald Clerk's engine (1880), a separate charging cylinder was introduced, permitting a working stroke to take place every revolution. As the piston of this engine nears the end of its explosion stroke, it uncovers exhaust ports near the far end of the cylinder; at this time, the piston of the charging cylinder, having previously taken in a mixture of air and gas, delivers first a flow of air to flush the products of combustion through the exhaust ports, and then the explosive mixture. The returning piston covers the exhaust ports and compresses the charge before it into the clearance space, the explosion following.

Since then, several types of internal combustion engines working under somewhat different cycles have been placed in successful operation, but the *great majority* of the *standard types* of the latest makes *work on the four-cycle principle.*

Some of the more important types of all classes are described in detail in Chapters—XV to XXI.

CHAPTER II.

LAWS OF PERMANENT GASES.

10. **Definition of a Permanent Gas.** Since the year 1877, when Cailletet and Pictet succeeded in liquefying hydrogen and other gases, the term *permanent* as applied to a gas signifies merely that the gas is capable of being liquefied only with great difficulty, either by the use of a very low temperature, or an extremely high pressure, or by the combined effect of both.

It is a fact, however, that so long as gases exist or act under conditions which are widely different from those required for liquefaction, they conform very nearly to certain simple laws which may be considered as rigorously applicable to ideal substances that may be called perfect or permanent gases.

These laws are as follows:

11. **Boyle's Law.** About the year 1662, Robert Boyle of England, discovered that—

At a constant temperature, the volume of a given weight of gas varies inversely as the pressure.

The same law was also independently discovered and announced by the physicist Edmé Mariotte of France about twelve years later, (1674), and is, therefore, often recognized as Mariotte's law.

According to this law, if V_1 represents the initial volume of a given mass of gas expressed in any unit of cubical measure, as cubic feet, cubic inches, etc., and P_1 the initial pressure, expressed in any unit of pressure on a unit of area, as pounds per square foot, pounds per square inch, etc., then for any variations of pressure and volume, so long as the temperature

remains unchanged, the pressure multiplied by the corresponding volume gives the same result, or—

$$P_1 \ V_1 = \text{constant}; \dots\dots\dots\dots\dots\dots (a)$$

and for any other volume V_2 and pressure P_2

$$V_1 : V_2 :: P_2 : P_1;$$

or more conveniently

$$V_1 \ P_1 = V_2 \ P_2;$$

from which we derive the expressions—

$$\frac{\textit{Initial volume} \times \textit{Initial pressure}}{\textit{Final volume}} = \textit{Final pressure} \dots\dots (b)$$

$$\frac{\textit{Initial volume} \times \textit{Initial pressure}}{\textit{Final pressure}} = \textit{Final volume} \dots\dots (c)$$

or as expressed in symbols—

$$\frac{V_1 P_1}{V_2} = P_2; \qquad \text{and} \qquad \frac{V_1 P_1}{P_2} = V_2.$$

For example: If a given weight of gas, having a volume of 20 cubic inches, and a pressure of 14.7 pounds per square inch at a temperature of 32° Fahr., be compressed to 10 cubic inches, its temperature in the meantime being kept constant, then by the equation (*b*) its pressure will be increased to $20 \times 14.7 \div 10 = 29.4$ pounds per square inch, or the final pressure will be double the initial pressure.

On the other hand, if the original volume of 20 cubic inches be expanded to 40 cubic inches, while its temperature is kept constant the pressure of the gas will be reduced to $20 \times 14.7 \div 40 = 7.35$ pounds per square inch, or the final pressure will be one-half the initial pressure.

Similarly, if the initial volume, the initial pressure, and the final pressure are known, the final volume of a given weight of gas under conditions of expansion and compression at a constant temperature may be ascertained by means of the expression (c).

Another important fact established by this law refers to the density of a gas. It is clear, that since the density of a given weight of gas will vary inversely as the volume, the pressure must vary directly as the density, and, therefore, will be directly proportional to it at the same temperature; or

$$P_1 : P_2 : : D_1 : D_2;$$

and

$$\frac{P_2}{D_2} = \frac{P_1}{D_1} = \text{constant}.$$

It will be noted, that since the foregoing law defines the action of a gas while its temperature is kept constant, it is not wholly applicable to the action of a gas, for example such as that used in the cylinder of a gas engine, the action of which is due to variations of temperature which cause corresponding variations of volume and pressure.

12. **Gay-Lussac's Law.** About the year 1802, the eminent physicist, Gay-Lussac of France, discovered that different gases expanded in the same proportion when heated from 0° to 80° Réaumur, and announced the general law, that—

At constant pressure, equal volumes of different gases increase equally for the same increment of temperature; also, that equal increments of volume correspond very nearly to equal intervals of temperature as indicated by the scale of a mercurial thermometer.

This law was recognized some years previously by Charles of England, and is therefore sometimes referred to as *Charles's law;* but the credit of its establishment as one of the fundamental bases of modern chemistry belongs beyond question to the eminent genius of Gay-Lussac.

13. **Absolute Temperature.** According to Gay-Lussac's law, equal volumes of hydrogen, oxygen, air, etc., at 32° Fahrenheit, if kept at a constant pressure, not necessarily the same for all, and heated through 1° Fahr., will increase in volume in each case by $\frac{1}{493}$ of the original volume. Therefore, if the original volume of any gas at 32° Fahr., is 493 cubic inches, it will be 494 cubic inches at 33° Fahr., 495 cubic inches at 34° Fahr., etc. Also, if the temperature be reduced, the original volume will contract by $\frac{1}{493}$ of itself for each degree of temperature below 32° Fahr. Therefore, at 0° Fahr., the volume will be $493-32=461$ cubic inches, and at 461° below 0° Fahr., the volume will be 0; or in other words, if a perfect gas be cooled to a temperature of $-461°$ Fahr., it will have neither volume nor pressure and will, therefore, establish an ideal point from which all temperature may be counted as Zero.

For this reason, the point at which a permanent gas is completely stable is called the *Absolute Zero of Temperature,* and the absolute temperature as indicated by a thermometric scale will be the thermometric temperature plus the number of degrees included between its zero point and the absolute zero of temperature, as determined by its particular scale.

In the case of the Fahrenheit thermometer, this value as already explained is 461°, therefore, all Fahrenheit temperatures may be converted into absolute temperatures as follows:

32° Fahr.+461°=493° absolute; 64° Fahr. +461°=525° absolute; etc.

In the case of the Centigrade thermometer, the fraction representing the increment of the volume of a gas for each additional degree of temperature, or *vice versa*, is $\frac{1}{273}$. This is due to the assumption of the zero point of its scale at a point of temperature corresponding to the temperature of 32° Fahr., and the division of the interval of temperature between 32° Fahr., the freezing point of water, and 212° Fahr., the boiling point of water, which is equal to 180 Fahrenheit degrees, into 100 centigrade degrees, thus making 1° centigrade equivalent to 1.8° degrees Fahrenheit. Therefore, since the absolute zero of temperature lies 493° below 32° Fahr., its value according to the scale of the centigrade thermometer will be 493÷1.8=273; or − 273° C., and all centigrade temperatures may be converted into absolute temperatures as follows:

0° C.,+273°=273° absolute; 100° C.,+273°=373° absolute, etc.

14. **Absolute Zero of Temperature.** It is well to note, that the absolute zero of temperature as calculated by the expansion ratio of gases is equivalent to −460.66° Fahrenheit, or to 273.7° Centigrade, but the values given in the foregoing paragraph are near enough for all practical purposes, and much more convenient for use in extended computations.

15. **The Use of Absolute Temperatures.** By the use of absolute temperature values in computations and formulae, all temperature readings are made positive throughout the range of experience and practice, thus eliminating the negative readings which result from the arbitrary location of the zero point of the ordinary thermometric scales relatively to the freezing

point of water. Furthermore, since the absolute zero of temperature represents a point at which a gas has neither volume nor pressure, the use of absolute temperature values affords expressions which include in the same number both the increment of temperature and the increment of volume.

16. **Absolute Pressure.** While considering the matter of absolute values it is well to understand that the term absolute zero of pressure does not in any way refer to the pressure of a gas at the absolute zero of temperature.

Absolute pressure values refer to the pressure of a gas above or below that of normal atmospheric pressure, 14.7 pounds per square inch, against which the effective power of a gas in the cylinder of a heat engine must continually act.

Since the lowest pressure that can be produced in nature is that which results from the removal of the atmospheric pressure from a vessel by the creation of a Torricellian vacuum therein, the absolute zero of pressure is 14.7 pounds below the zero of an ordinary pressure gauge, and the absolute pressure is the recorded or gauge pressure plus 14.7 pounds.

For example: 12.5 pounds gauge pressure $+ 14.7 = 27.2$ pounds absolute, all values of course representing pressure in pounds per square inch.

17. **Boyle's Law Applied to Gay-Lussac's Law.** According to Boyle's law, when the absolute temperature of a gas is constant, the volume multiplied by the pressure always gives the same result; but according to Gay-Lussac's law, at constant pressure the volume of a gas varies directly as the absolute tem-

perature, or at constant volume the pressure varies directly as the absolute temperature. In other words, the pressure or the volume of a gas is directly proportional to its absolute temperature.

Therefore, if V_1 be the volume of a given weight of gas at absolute temperature T_1, and V_2 the volume at absolute temperature T_2; then—

$$V_1 : V_2 :: T_1 : T_2,$$

or

$$V_1 T_2 = V_2 T_1,$$

whence

$$\frac{V_1 T_2}{T_1} = V_2 \quad \ldots\ldots\ldots\ldots (d)$$

or, if P_1 be the pressure for absolute temperature T_1, and P_2 the pressure for absolute temperature T_2; then—

$$P_1 : P_2 :: T_1 : T_2,$$

and

$$P_1 T_2 = P_2 T_1,$$

whence

$$\frac{P_1 T_2}{T_1} = P_2 \quad \ldots\ldots\ldots\ldots (e)$$

also

$$\frac{P_2 T_1}{P_1} = T_2 \quad \ldots\ldots\ldots\ldots (f)$$

The expressions (d), (e), and (f), may also be stated as follows:

$$\frac{\textit{Initial volume} \times \textit{Final temperature}}{\textit{Initial temperature}} = \textit{Final volume} \ldots\ldots (d)$$

$$\frac{\textit{Initial pressure} \times \textit{Final temperature}}{\textit{Initial temperature}} = \textit{Final pressure} \ldots (e)$$

$$\frac{\textit{Final pressure} \times \textit{Initial temperature}}{\textit{Initial pressure}} = \textit{Final temperature}\ (f)$$

and indicate the mutual relations of the initial and final volumes, pressures, and temperatures of a gas acting under the influence of heat within a closed vessel, such as the cylinder of a gas engine.

For example: If 20 cubic inches of gas at a temperature of 525° absolute, be placed in a cylinder, and heated to a temperature of 2811° absolute, then by formula (*d*) its volume will increase to

$$\frac{20 \times 2811}{525} = 107 \text{ cubic inches;}$$

but its pressure will remain unchanged.

Suppose, however, the initial pressure of the gas to be 14.7 pounds per square inch, and that the gas is not allowed to expand when heated; then by formula (*e*) its pressure will increase to

$$\frac{14.7 \times 2811}{525} = 78.7 \text{ pounds per square inch.}$$

Now suppose, that it is required to determine the absolute temperature of explosion of a gas, and the following values are known—compression pressure 65 pounds absolute; compression temperature 800° absolute; pressure of explosion or final pressure 250 pounds absolute; then by formula (*f*) –

$$\frac{800 \times 250}{65} = 3077° \text{ absolute or } 2606° \text{ Fahr.}$$

18. Specific Heat of Gases. According to the two laws stated in the foregoing paragraphs, the capacity of a given mass of gas for doing work depends—first, upon its volume, or the amount of space it occupies; and second upon its absolute temperature.

An all important factor in this connection is the heat absorbing capacity of a gas, as related to its temperature, or the amount of heat required to raise the temperature of a given mass of the gas by one degree of a thermometer scale.

Therefore, if **W** represents the mass of a given body of gas and **C** its specific heat, the internal energy of the body of gas at a temperature T will be represented by the expression

$$W \times C \times T.$$

It is evident, however, that the temperature of a gas may be increased under difficult conditions of pressure and volume, that is, the heating may be at constant pressure or at constant volume. Therefore a gas must have two specific heats.

19. Specific Heat at Constant Pressure. The specific heat at constant pressure is the amount of heat absorbed by the unit mass of gas when its temperature is raised by one degree on the thermometric scale, the pressure being kept constant, but the volume being allowed to increase.

20. Specific Heat at Constant Volume. The specific heat at constant volume is the amount of heat absorbed by unit mass of the gas when its temperature is increased by one degree on the thermometric scale, its volume being kept constant, so that the addition of heat results in an increase of pressure.

Since a gas when heated at constant pressure necessarily expands and does work on the external air, the specific heat at

constant pressure is necessarily greater than that at constant volume by the amount of the heat used up in doing that work. Therefore, the specific heat at constant volume is commonly known as the true specific heat; but both values require to be considered in connection with gas engine problems.

21. **Regnault's Law.** Regnault determined by experiment, *that the specific heat at constant pressure is constant for any gas.*

Therefore, if C_p represents the specific heat at constant pressure, and C_v the specific heat at constant volume, and a unit mass of gas be heated at constant pressure **P** from absolute temperature T_1 to absolute temperature T_2; then

$C_p\,(T_2-T_1) =$ Heat absorbed........................(g),

Now, if V_1 be the volume of the gas at T_1 and V_2 the volume at T_2; then

$P\,(V_2-V_1) = d\,(T_2-T_1) =$ External work performed (h),

in which **d** is a constant that depends upon the specific density of the gas and on the units in which **P** and **V** are measured; and the difference between the quantities (g) and (h), or $(C_p-d)\,(T_2-T_1)$ represents the increase in the amount of the internal energy of the gas when its temperature is raised from T_1 to T_2.

It can be shown, further, that this increase of internal energy will be the same if the gas be heated in any manner whatever from T_1 to T_2.

22. **Joule's Law.** From actual experiments Joule ascertained, *that when a gas expands without doing external work, and without taking in or giving out heat, its temperature remains unchanged.*

In other words, that changes of pressure and volume not connected with changes of temperature do not effect the internal energy of a gas. Therefore, in any change of temperature the change of internal energy is independent of the relation of pressure to volume, and when two states of a gas are compared, the internal energy depends upon their difference of temperature and not upon the difference of pressure.

It has been shown that

$$(C_p - d) = (T_2 - T_1),$$

represents the increase of internal energy when the gas is heated from T_1 to T_2 at constant pressure; therefore, the same quantity represents the increase of internal energy when the temperature of the gas is changed from T_1 to T_2 in any manner whatsoever.

Now, take the case of a unit weight of gas heated from T_1 to T_2 at constant volume.

$$C_v\,(T_2 - T_1) = \text{Heat absorbed.}$$

The gas does not expand, however, therefore no external work is done, and all of the heat absorbed represents increase of internal energy, so that

$$C_v\,(T_2 - T_1) = (C_p - d)(T_2 - T_1);$$

and $W \times C_v (T_2 - T_1)$ represents the available internal energy of a given mass of gas heated from T_1 to T_2 ; and for any gas

$$C_p - d = C_v;$$

or, the specific heat at constant pressure is greater than the specific heat at constant volume by the amount of the external work done by the expansion of the gas.

The following table gives the values of the properties of different gases which will be found useful in connection with gas engine calculations.

23. Table of Properties of Gases.

	Specific Gravity.	Weight of One Cubic Foot in Lbs.	Volume of One Pound in Cubic Feet.	C_p Specific Heat at Constant Pressure.	C_v Specific Heat at Constant Volume.	Ratio $\frac{C_p}{C_v}=y$
Air....................	1.0000	0.080728	12.387	0.237	0.168	1.406
Oxygen (O)............	1.1051	0.08921	11.209	0.217	0.155	1.403
Nitrogen (N)...........	0.9714	0.07842	12.752	0.244	0.173	1.409
Hydrogen (H)..........	0.0695	0.00561	178.230	3.409	2.406	1.417
Marsh Gas (CH_4).......	0.5560	0.04488	22.301	0.593	0.467	1.270
Ethylene (C_2H_4).......	0.9847	0.07949	12.580	0.404	0.332	1.144
Carbonic oxide (CO)....	0.9674	0.07810	12.804	0.245	0.173	1.416
Carbon dioxide (CO_2)...	1.5290	0.12343	8.102	0.216	0.171	1.165
Steam (H_2O)............	......	0.03794	26.42	0.480	0.369	1.302

Note.—All the values, with the exception of those of steam, are given at normal atmospheric pressure (14.7 pounds per square inch) and at 32° Fahr. Steam at 212° Fahr.

When the mass per cubic foot of gas, and its coefficient of expansion under the influence of heat are known, the values of d for any gas may be computed as follows:

Imagine a cylinder one square foot in area having a piston working within it against the normal pressure of the atmosphere 14.7 pounds per square inch. The total pressure on the piston will be $14.7 \times 144 = 2116.8$ pounds. Let one cubic foot of air be placed in the cylinder under the piston, and expand it by the application of heat to two cubic feet. The work done by the cubic foot of air will be 2116.8 foot-pounds; and since a cubic foot of air under the assumed conditions of pressure and temperature weighs .080728 of a pound, the work that may be done by one pound of air will be $2116.8 \div .080728 =$ 26217.6 foot-pounds.

Now, according to Gay-Lussac's law, increase in temperature equal to 493° Fahr., or 273° Centigrade, is required to double the volume of a gas which is at 32° F. or 0° C.; therefore, the external work which will be done by the gas when its temperature is raised one degree will be $\frac{1}{493}$ of that done when its temperature is raised 493°, and the external work which is required of air, when its temperature is raised by one degree Fahrenheit, will be $26217.6 \div 493 = 53.3$ foot-pounds $= \mathbf{d}$, or the amount by which the specific heat of air at constant pressure is greater than its specific heat at constant volume, expressed in work units.

CHAPTER III.

THEORETICAL WORKING PRINCIPLES.*

24. Action of Heat Engines. All heat engines operate through the medium of a working substance which receives heat, converts a small portion of that heat into mechanical energy, and rejects the remainder still in the form of heat.

25. Nature of Working Substances. The working substance may be a solid, a liquid, or a gas, and the action of the engine may be due to changes of either the form and the volume of its working substance, or to changes of volume alone.

The theory of this action is based upon well-known principles which may be stated as follows:—

26. Laws of Thermodynamics. 1. In the conversion of heat into mechanical energy, one unit of heat is lost for every 778 foot-pounds of energy obtained; and conversely, in the production of heat by mechanical means, one unit of heat is obtained from every 778 foot-pounds of energy expended. (Joule). 2. It is impossible for a self-acting engine to convey heat from one body to another at a higher temperature without external aid. (Clausius).

27. Thermal Efficiency. According to the first law, there is nothing to prevent an engine from converting all of the heat supplied to it into mechanical energy, and its efficiency may be expressed by 1 or unity; but according to the second law, no heat engine can convert into mechanical energy more than a

small fraction of the heat supplied to it, the greater portion being necessarily lost in various ways; in overcoming the molecular resistance of the working substance to changes of form; in overcoming the friction of the working parts of the mechanism; and by rejection, so that the efficiency becomes the ratio—

$$\frac{\textit{Heat converted into work}}{\textit{Heat absorbed by the working substance}},$$

which is a fraction always much less than unity, and represents the thermal efficiency of an engine operating under actual working conditions.

28. A Solid Working Substance. *For example;* imagine a heat engine in which the working substance is a solid metallic rod arranged to act as a pawl against the teeth of a cogwheel. Let the rod be heated by the application of fire until it elongates sufficiently to push the wheel forward through the space of one tooth, and then let it be cooled by the application of cold water until it contracts to its original length. In the meantime, if by means of suitable arrangements the wheel were prevented from turning backwards to its original position, the rod will bear against the next succeeding tooth, and if reheated will elongate again and push the wheel forward through the space of another tooth, so that, by alternately heating and cooling the rod, a continuous rotary motion could be imparted to the wheel, and the entire arrangement would be a heat engine with a solid for a working substance.

In this case, however, the amount of heat actually converted into mechanical energy is so small relatively to the amount of heat absorbed by the working substance, that the thermal efficiency ratio is far below the minimum limit required for prac-

tical purposes; but the example serves to demonstrate that the action of the engine is primarily due to a difference of temperature, or to the "temperature range" through which its working substance acts.

29. **The Action of a Working Substance.** The principle of action thus exemplified may be summarized as follows: the working substance receives heat from a source of supply, thus rising to a high temperature, converts a small portion of it into mechanical energy, thus falling to a lower temperature and is then rejected. In other words, a heat engine performs work by dropping the working substance from a high to a low temperature in a manner somewhat similar to the action of a water wheel, which performs work by dropping water from a high to a low level; with this difference, however, that in the case of the heat engine a certain amount of heat is lost or converted into mechanical energy in the process of transfer, and represents the amount of work performed by the engine.

In the case of the water wheel, the point from which the water drops, and the point at which the wheel is located, respectively represent the upper and lower limits of the range of elevation through which the water acts in the conversion of the potential energy of gravity into kinetic energy, and it is easily understood that an increase of the upper limit or the height of the fall will result in an increase of the amount of natural energy available for conversion into mechanical energy, and consequently in an increase of the hydraulic power of the water wheel arrangement.

The amount of energy abstracted from any source and rendered available, when expressed as a fraction or percentage of the whole is termed the *efficiency* of the working substance.

30. The Temperature Range. Likewise, in the case of the heat engine, the temperature at which the working substance is received, and the temperature at which it is rejected by the engine,respectively represent the upper and lower limits of the temperature through which its working acts, and determines the number of heat units available for conversion into mechanical energy. Therefore, if the temperature range be increased either by raising its upper limit, or by decreasing its lower limit, or by the combined increase of the one and the decrease of the other, the result will be an increase in the amount of heat available for conversion into mechanical energy, and consequently an increase of the thermal efficiency of the engine.

31. Maximum Thermal Efficiency. As the thermal efficiency of an engine represents its power producing capacity on the basis of the amount of heat actually converted by it into mechanical energy, the thermal efficiency of an engine as determined by its temperature range is the ratio—

$$\frac{\textit{Temperature of reception} - \textit{Temperature of rejection}}{\textit{Temperature of reception}},$$

which represents the maximum thermal efficiency of an engine, and defines a limit that no heat engine whatsoever can exceed. (Carnot).

Returning to the case of the engine with the metallic rod for a working substance, it is clear that the method of heating and cooling employed, and the nature of the working substance, establish the upper and lower limits of a temperature range which cannot be materially increased. Therefore, an increased thermal efficiency ratio with the same temperature range can be attained only by substituting for the metallic rod a working substance

which will be elongated or expanded to a greater extent by the application of the same amount of heat.

For natural reasons, liquids expand more than solids under the influence of a given temperature. Therefore, the thermal efficiency of a heat engine using a liquid for a working substance will be greater than that of one using a solid.

32. **A Liquid Working Substance.** The best example of a heat engine using a liquid for a working substance is the ordinary steam engine in which the original working substance is water, and the ultimate working substance is saturated steam. For various reasons which need not be given in this connection, it is impossible to make a direct comparison between the thermal efficiency of a steam engine and one operating with a metallic rod for a working substance. The methods of heating and cooling, and the conditions upon which the limiting temperatures of the respective temperature ranges depend are entirely different in the two cases; but, in order to thoroughly understand the exact relation of the temperature range to the thermal efficiency of an engine, and especially to that of a gas engine which is the ultimate object of this consideration, it is necessary to clearly appreciate the limitations of the various types of steam engine in this respect.

The following example will serve to illustrate the cycle of action of a liquid working substance, in one phase of which it assumes a semi-gaseous condition and thus approximates to the ideal working substance of a heat engine, on the basis; that as a liquid expands more than a solid under a given temperature, for similar reasons a gas will expand more than a liquid.

33. **Action of a Semi-gaseous Working Substance.** Imagine a cylinder with an area of one square foot, having a close-fitting piston working within it. Assume that the cylinder contains one pound of water at a temperature of 32° Fahrenheit, rising to a height of 0.016 of a foot, and bearing upon its surface the weight of the piston under the normal pressure of the atmosphere (14.7 pounds $\times$ 144 square inches $=$ 2116.8 pounds). Upon the application of heat to the bottom of the cylinder, the temperature of the water will rise from 32° to 212.5° Fahr., a little above the boiling point of water, before it will begin to form into steam and exert a lifting pressure against the piston, thus using up 212.5° $-$ 32 $=$ 180.5 heat units, which, consequently, will not be available for conversion into mechanical energy. If the application of heat be continued, all of the water will be ultimately converted into a body of steam having a volume of 26.36 cubic feet. This operation will require an additional expenditure of 966.1 heat units, making a total of 1146.6 heat units expended in raising the piston to the corresponding height of 26.36 feet. The heat units, necessary to change water into steam, without change of temperature, constitute the *latent heat of steam.*

34. **Work Performed by Saturated Steam.** The amount of heat stated above will have been expended in two ways—first, in overcoming the internal molecular resistance of the water in converting it into steam; and second, in overcoming the atmospheric pressure on the piston, or the resistance of the piston to the increasing volume of the steam during its formation. The first is the *internal work,* and the second is the *external work* performed by the steam, and the amount of heat expended in each operation may be determined as follows:

Total heat expended is 1146.6 heat units. To raise a piston against a pressure of 2116.8 pounds to a height of 26.36 feet, requires the expenditure of 26.36 feet$\times$2116.8 pounds$=$55,798.8 foot-pounds of energy. As one heat unit is equivalent to the mechanical energy represented by 778 foot-pounds, then 55,798.8$\div$778$=$71.7 heat units expended in raising the piston or doing external work. This amount added to the 180.5 heat units expended in raising the temperature of the water from 32° to 212.5° Fahr., gives 252.2 heat units expended in heating the water and raising the piston, which amount substracted from the total amount of heat expended, gives 1146.6 $-$ 252.2 $=$ 894.4 heat units expended in internal work of converting water into steam.

It is clear, that under the conditions assumed, only a small fraction 71.7$\div$1146.6$=$.06, or about six per cent of the total heat supplied to, or absorbed by, the working substance is converted by it into mechanical energy.

35. Effect of Pressure on Thermal Efficiency. Now, with all the other conditions remaining the same as above, assume that an additional weight of 87.2 pounds is placed on the piston, making the pressure 14.7$+$87.2$=$101.9 pounds absolute. In this case, in consequence of the greater pressure, the steam will not begin to form until the water has been raised to a temperature of 329° Fahr., thus using up 299.5 heat units, and it will require 882.7 additional heat units to convert all the water into steam, making a total of 1182.2 heat units expended in raising the piston to the height of 4.28 feet, corresponding to the volume the steam will occupy under the greater pressure. The amount of heat converted into mechanical energy will be 80.7 heat units, or more than seven per cent. of the total

amount of heat supplied, which shows the advantage of an increase of the temperature of reception or the value of a high initial temperature within the working cylinder.

36. **Maximum Thermal Efficiency of Steam Engine.** Referring to the maximum thermal efficiency formula; if T_1 is put for the temperature of reception or initial temperature, and T_2 for the temperature of rejection or final temperature, then—

$$\frac{T_1 - T_2}{T_1} = \text{Maximum Thermal Efficiency.}$$

Assuming a condensing temperature of 32° Fahr., the resulting thermal efficiency ratios are as follows:

In the first case, $T_1 = 212.5°$ Fahr. $+ 461° = 673.5°$ absolute; and $T_2 = 32°$ Fahr. $+ 461° = 493°$ absolute, and by the formula—

$$\frac{673.5° - 493°}{673.5°} = 0.27 \text{ or } 27 \text{ per cent.}$$

In the second case, $T_1 = 790°$ absolute, and $T_2 = 493°$ absolute, which gives a maximum thermal efficiency of 0.37 or 37 per cent.

Both cases represent the action of engines using saturated steam, but the thermal efficiency ratios are those corresponding to ideal and not to practical working conditions. They serve, however, to establish two important facts—the value of a high initial temperature within the working cylinder; and second, that in the case of engines using saturated steam, an increase of the initial temperature within the working cylinder can be obtained only by increasing the pressure or load on the piston, or in other words, the gain of thermal efficiency is obtained at the expense of mechanical complication.

37. **Gaseous Working Substance.** In the case of the steam engine, using saturated steam, the pressures which constitute the loads on the piston soon become unmanageable as they require the adoption of heavy, cumbersome, and uneconomical types of engine to withstand the unusual strains and stresses developed by their application. Therefore, it is evident that any further development of the steam engine towards the attainment of a higher thermal efficiency must be accomplished by changing the physical form of its working substance. This is practically done by superheating the steam. This means, that after the water in the boiler has been converted into steam and taken from the boiler, it is further heated until its temperature is raised to considerable over 300° Fahr., thus practically changing its condition to that of a permanent gas—the ideal working substance for a heat engine. As the steam thus superheated is admitted to the cylinder at the increased pressure due to the addition of heat while its volume remained unchanged, the temperature of the superheated steam becomes the initial temperature within the working cylinder, and results in an increase of the temperature range or an increase of thermal efficiency without a corresponding increase of the load on the piston.

It is true that by excessive superheating an ideal thermal efficiency of about 40 per cent. can be attained in the steam engine, but the application of the method practically converts the external combustion steam engine into an internal combustion engine using steam-gas for a working substance.

38. **Effect of Superheating.** As superheated steam is practically a permanent gas—the ideal working substance for a heat engine, it is evident that any further increase of thermal

efficiency must be obtained by the adoption of a method of heating which will prevent the enormous losses of heat due to radiation, and to the necessity of changing the physical form of the working substance.

Theoretically, superheating has the effect of transferring the furnace from the boiler to the working cylinder of the engine. In other words, the method of indirect heating, characteristic of the external combustion engine, is replaced by the method of direct heating which distinguishes the internal combustion or gas engine method, and suggests the next logical step towards the attainment of a higher thermal efficiency.

39. **The Gas Engine Method.** The gas engine represents the practical transference of the furnace from the boiler to the working cylinder. This is accomplished by the use of a permanent gas, atmospheric air, for the working substance, which is intimately mixed with a fuel, also in the form of a gas. This mixture constitutes the charge which is introduced into the working cylinder of the engine and there ignited by means of a flame or other source of high temperature. The resulting combustion liberates the inherent heat of the fuel component of the mixture and applies it directly to every molecule or particle of the air component or working substance, thus increasing its temperature and pressure and causing it to drive the piston.

40. **Increase of Thermal Efficiency Independent of Piston Load.** By the application of the gas engine method, the initial temperature within the working cylinder is not only made independent of the load on the piston, but also may be increased in various ways, which require, for their proper analysis, the division of the practical working cycle of a gas engine into its two

component parts—*the cycle of action of the working substance,* and the *cycle of action of the mechanical arrangement;* and the consideration of the two cycles both separately and conjointly.

In order to facilitate such a consideration, imagine a cylinder of non-conducting material, 10 square inches in area, and having a piston working within it, against the pressure of the atmoshere only with a 10-inch stroke from A to B, as shown in *Fig.* 8.

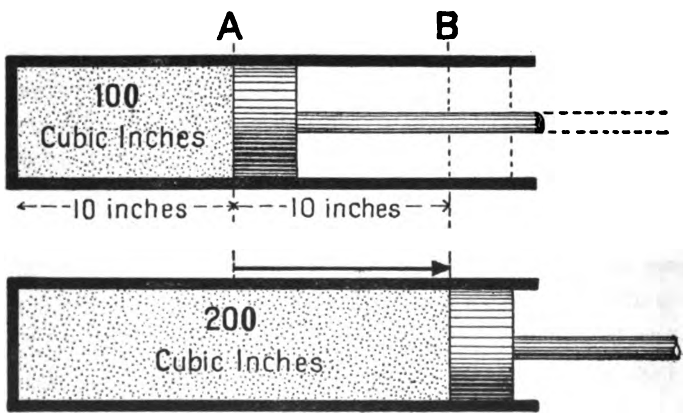

Fig. 8.—(Paragraph 39-42.)

41. **Igniting without Previous Compression.** First; suppose that a volume of 100 cubic inches of an inflammable gas having a temperature of 493° absolute, is introduced into the cylinder at atmospheric pressure and ignited to a temperature of 986° absolute, when the piston is at the beginning of its outward stroke. According to Gay-Lussac's law, the gas will expand to a volume of $100 \times 986 \div 493 = 200$ cubic inches, or to two times its original volume, and drive the piston to its outer limit **B.**

During this operation, the pressure on the piston, 14.7 pounds per square inch, will have remained unchanged, but the pressure exerted against the piston by the expanding gas would have amounted to $14.7 \times 2 = 29.4$ pounds per square inch.

42. **Igniting with Previous Compression.** Second; suppose that instead of igniting the gas when the piston is at the point A, at the beginning of its forward stroke, the admission of gas is continued until it completely fills the cylinder at the end of the outward stroke. The volume of the gas will then be equal to 200 cubic inches, and if it were compressed to 100 cubic inches by the return stroke of the piston, and then ignited at a temperature of 986° absolute, it will expand to four times its compressed volume and develop a pressure sufficient to drive the piston through a 40-inch stroke.

This operation represents in a general way the effect of compression in its relation to the ratio of expânsion, but it must be understood, that the compression pressure constitutes a load on the piston, and that the actual advantage of its application is due to other conditions besides the mere reduction of the original volume of the gas prior to ignition. All of these conditions will be found properly considered under *Compression* as employed in actual gas engine practice in Chapter X. *See paragraph* 127.

43. **Heating at Constant Volume.** Third; suppose that in either of the foregoing cases, instead of allowing the piston to move forward it were held fast after ignition, thus preventing the expansion of the gas due to the increase of temperature. Then, the pressure of the gas would rise to 29.4 pounds per square inch in the first case, and to 58.8 pounds per square inch

in the second, and represent the static energy of the gas available for doing work in the respective cases.

The increase of the temperature and the pressure of the gas while its volume remained unchanged, thus exemplified, exactly represents the conditions which obtain behind the piston of a gas engine while the crank is passing over its inner dead center, so that the pressure behind the piston is suddenly increased before the latter can move forward and relieve the pressure by allowing the gas to expand.

This is called heating at constant volume, with increase of temperature and pressure, and conforms to a law which might be stated as follows—

"The initial temperature divided by the initial presssure equals any other temperature divided by the pressure at that temperature."

44. Ignition Temperature and Temperature of Inflammation. In the first case; since the ignition temperature corresponds to the inflammation temperature of the gas, the increase of thermal efficiency depends upon the nature of the working substance. Therefore, it is related to the cycle of the working substance but independent of the cycle of the machine.

45. Ratio of Expansion. In the second case; since the high thermal efficiency due to the increased temperature range is made practically effective by the larger ratio of expansion provided by compression due to the application of a load on the piston, the factor of compression is the connecting link between the cycle of the working substance and the cycle of the machine.

46. Practical Working Cycle of an Engine. In the third case; the cycle of the working substance and that of the machine are combined into one cycle of operations, which constitutes the practical working cycle of the engine, and represents, in this particular case, that of a gas engine heating at constant volume.

In all of the foregoing cases, the values assumed for temperature and volume are purely arbitrary.

In the case of engines acting under actual working conditions, great variations occur in these values according to the nature of the working substance, and the conditions of temperature, volume, and pressure, which obtain at heating; while the cycle of the machine determines the nature of the initial and final temperatures, volumes and pressures, the values of which may be substituted for the corresponding symbols in the thermal efficiency and other formulae applicable to computations relative to gas engine performance.

Although these matters will be more fully considered in the following chapters for the purpose of showing how nearly the theoretical values are approached by those attained in practice, the following figures are here introduced to afford a general comparison of the thermal efficiency values of gas engines and steam engines as determined by the maximum thermal efficiency formula.

47. Theoretical Thermal Efficiency of a Gas Engine. The working substance of a gas engine and the fuel gas which is used form a mixture, the ignition temperature of which varies with the proportion of air to gas, and also according to the chemical constituents of the gas. For mixtures of olefiant gas ($C_2 H_4$), air, and oxygen, the temperature of ignition lies between 1152° and 1368° Fahr.

Assuming the ignition temperature of such a mixture at 1200° Fahr., as the maximum temperature of the cycle of the working substance, and an exhaust temperature of 64° Fahr., the maximum thermal efficiency formula gives—by the substitution of the corresponding absolute temperatures—

$$\frac{1661° - 525°}{1661} = 0.68$$

for the theoretical thermal efficiency of a gas engine using that particular mixture.

48. **Heat Balance of a Gas Engine.** It will be understood, however, that as an actual engine differs in many particulars from a theoretical engine, the heat losses sustained by the working substance during the operation of the practical working cycle of an engine tend to materially reduce the value given above.

Some idea of the distribution of these losses is afforded by the following table, which shows the disposition of 100 heat units absorbed by the working substance of a gas engine operating under a practical working cycle of four phases—a four-cycle engine.

Heat converted into mechanical energy	22
Heat lost to cylinder walls	53
Heat lost in exhaust gases	14
Heat lost by conduction and radiation	11
	100

The actual indicated thermal efficiency is 22 per cent.

49. Actual Indicated Thermal Efficiency of Gas Engine. In the various types of gas, gasoline, and oil engine, this value ranges from about 10 to 27 per cent., according to the practical working cycle of the engine.

This shows, that in the case of a gas engine using a fuel gas of the highest calorific value, an increase of either the theoretical or actual indicated thermal efficiency, beyond that due to the temperature range limited by the ignition temperature of the mixture in the first case, or the explosion temperature of the mixture in the second case, can be attained only by the adoption of practical working cycles which will establish the most effective relation between the cycle of the working substance and the cycle of the machine.

An interesting example of this character is afforded by the Diesel engine. Heating at constant temperature, and using a very high compression, this engine has shown under test conditions a theoretical thermal efficiency of over 75 per cent., and an actual indicated thermal efficiency of about 38 per cent. These values are much higher than those attainable by any other types of heat engine.

50. Actual Indicated Thermal Efficiency of the Steam Engine. In the various types of steam engine, this value rarely attains 12 per cent., a limit which is exceeded only by some types of pumping engine. A Reynolds' pumping engine at Boston, Massachusetts, is credited with a record of 187.8 B. T. U. per indicated horse-power, which corresponds to an actual indicated thermal efficiency of 22 per cent.

51. Relation of Temperature Range to Actual Indicated Thermal Efficiency. The foregoing comparisons serve to demonstrate, that in the case of actual engines, an increase of

the temperature range does not always result in an increase of actual indicated thermal efficiency. This is especially true with regard to compression engines operating with different working substances, and heating by different methods, and under varying conditions of temperature, volume, and pressure, of the working substance.

Triple-expansion steam engines using steam pressures ranging from 150 to 275 pounds per square inch absolute, have temperature ranges from 294° to 345° and attain actual indicated thermal efficiency values ranging from 12 to 22 per cent.

Gas engines operating under a compression pressure of 64 pounds per square inch, with a compression temperature of about 800° absolute—values applicable to normal expansion ratios, commonly develop explosion temperatures equal to 2,700° absolute, giving an effective temperature range of 1900°, and attain actual indicated thermal efficiency values ranging from 10 to 22 per cent.

Therefore, it is evident that a gas engine having a high temperature range may have a low actual indicated thermal efficiency, and that the reverse may be true in the case of a steam engine.

When comparing steam and gas engines, it should be remembered that the former make and throw away one working fluid, the furnace gases, in generating the second or actual working fluid, steam. The real efficiency, therefore, is the product of the efficiencies of the two fluids. Now, the gas-engine is its own generator, employing but one fluid, and that, as has been shown above, may have as high a thermal efficiency, in a single cylinder, as steam in a triple expansion engine. Consequently, the internal combustion engine, not being handicapped by a separate generator, is likely to be much more economical.

CHAPTER IV.

ACTUAL WORKING CYCLES.

52. **Practical Working Cycle Defined.** The *cycle* or *working cycle* of an engine is the complete circle of operations through which the working substance passes in one or more complete revolutions of the crank shaft. It includes the action of both components of the engine, the working substance and the machine.

At the beginning, it is well to clearly understand that the cycles of corresponding types of all internal combustion engines, gas, oil, or distillate, are similar in all particulars, the actual difference between any one class and any other being the manner in which the fuel is prepared prior to its introduction into the working cylinder.

Therefore, for convenience and brevity, the gas engine will be exclusively referred to in the following paragraphs, leaving the consideration of the particular differences between itself and the various types of gasoline, oil, and distillate engines for special treatment in Chapter XX.

53. **The cycle of a steam engine** embraces the admission of the steam into the cylinder, its expansion therein, and its subsequent exhaust and condensation.

54. **The cycle of a gas engine** embraces the admission of the charge into the working cylinder, its compression, ignition, combustion and expansion therein, and the subsequent exhaust of the burnt gases or products of combustion.

55. **Comparison of Steam and Gas Engine Cycles.** It will be noted that the cycle of a steam engine does not include the heating of the working substance within the working cylinder, that work being performed in the boiler by the combustion of the fuel in the furnace; while on the other hand, the cycle of a gas engine includes the combustion of the fuel and the heating of the working substance within the working cylinder. This difference clearly defines the working principle of all internal combustion engines, a principle which has already been referred to in the preceding chapter as the *gas engine method.*

56. **The Working Substance.** In the further consideration of this subject it is well to know the exact nature of the working substance of modern internal combustion engines. By writers and operators in general, it is variously called the *charge,* the *gaseous mixture,* the *explosive mixture,* the *mixture of gas and air,* the *fuel,* etc. An essential element of the working substance of an internal combustion engine of any kind is *atmospheric air.* A certain amount of this is admitted to the working cylinder together with a certain amount of fuel in the form of either gas or vaporized oil. The mixture of fuel and air forms the *charge;* which is usually so inflammable in character that it is, practically, an explosive.

By compression and ignition the fuel component of the charge is consumed and heats the air component, causing the latter to expand and drive the piston.

It is thus seen that the various gas engine cycles can differ from each other only in matters relating to the three fundamental conditions of the gas engine method—admission, compression, and ignition, while the nature of the working sub-

stance and the operations relative to exhaust and scavenging remain the same for all.

57. **Types of Gas Engines.** Under the foregoing conditions, all gas engines may be classified in three well defined types as follows: (1) Those in which a specified amount of charge is admitted to the working cylinder at atmospheric pressure and ignited without compression. (2) Those in which the charge is first compressed in an auxiliary cylinder, then admitted to the working cylinder under a definite constant pressure, and ignited as soon as it enters at the inlet valve. (3) Those in which a specified amount of charge is admitted to the working cylinder at atmospheric pressure, and ignited after being compressed by a return stroke of the piston.

58. **Lenoir and Hugon Engines.** Of the first type the two most successful engines were those of Lenoir and Hugon. They undoubtedly represent the simplest method of obtaining power by means of an explosion; but they were only made of small power, ranging from about one-man to half-horse, and as they are practically obsolete a discussion of their cycles is of no particular importance. *See Figs.* 1 *and* 2, *par.* 5.

59. **Brayton Engine.** The engines of the second type represent a more complex idea, and are notable as introducing the factor of compression. The most successful engine of this kind was that of Brayton. It was a closer approximation to the true solution of the gas engine problem than those of the first type, and small sizes were made in considerable numbers for some length of time. Like those of the first type it is now practically obsolete, and as the factor of compression must be completely considered in connection with the engines of the

third type, a discussion of its cycle is not necessary at present to give a clear understanding of the more important gas engine cycles. *See Figs.* 4 *and* 5, *par* 8.

60. Four-Cycle Type. The third type shows at the present time, the most successful solution of the gas engine problem, its best representative appearing to be the engine of the so-called four-cycle type.

The entire history of the idea represented by this type may be briefly stated as follows: The value of compression and ignition at constant volume was first suggested by Barnett in 1838, and was exhaustively treated by Beau de Rochas in 1860, who took out a patent for the idea in 1862. Nothing practical was accomplished, however, until 1878, when Otto, encouraged by the previous success of the Otto-Langen engine, built an engine in which he applied the cycle patented by Beau de Rochas, and thus produced the first really successful gas engine. *See Figs.* 6 *and* 7, *par.* 9.

During its commercial development this type of engine has passed through a great many changes of form in adapting it for various purposes, and for the production of a wide range of powers, from one-quarter to several thousand horse-power per engine unit, and although competing with several other efficient types of engines, particularly those of the so-called two-cycle type, it yet appears to be the one most capable of being adapted for varying requirements of use, fuel and amount of power.

It is made at the present time with either horizontal or vertical cylinders. Its ignition devices vary from the hot tube arrangement to various forms of electrical devices, but in all of the engines the working cycle remains the same as originally conceived by Beau de Rochas.

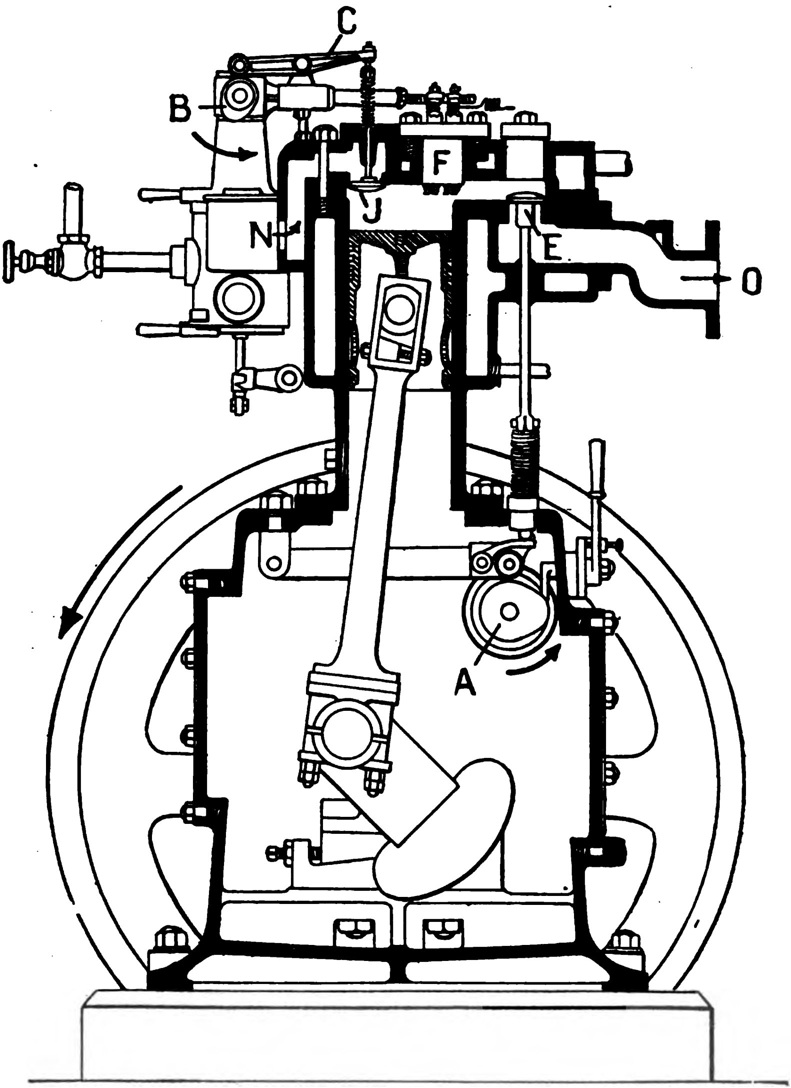

Fig. 9.—Four-Cycle Engine (Paragraph 60)

Referring to *Figs.* 9 and 10, this type may be described as follows:

Fig. 9, represents a section through the cylinder of a vertical engine. Such an engine may consist of one, two, three, or more cylinders placed side by side, all of them being exactly alike, and operating in precisely the same manner, but independently of each other. The cylinders are usually mounted upon an inclosed crank case which forms the base of the engine and also serves as a receptacle for the lubricating oil used upon the cranks and upper journals of the connecting rods. The engine is single acting, a feature almost absolutely necessary in a gas engine as the use of stuffing boxes is practically impossible owing to the rapid deterioration of the piston rods when they are exposed to the powerful action of the burning gases within the cylinder. The intermittent pressures exerted on the top of the piston by the exploding charges are converted into rotary motion at the crank shaft by means of a simple trunk piston, the wrist pin of which is linked to the crank by a short and massive connecting rod.

The valves are operated by a system of gearing, the utility of which will be clearly seen while considering the successive operations that constitute the cycle.

In the figure the piston is shown in the position that it would occupy immediately after the charge had been exploded in the clearance space at the upper end of the cylinder. The pressure exerted by the explosion drives the piston downwards on the power stroke and carries the crank through half a revolution. During this movement, the cam A is carried through one-quarter of a revolution, and at the instant the piston starts upwards on its scavenging stroke, it lifts the exhaust valve E through which

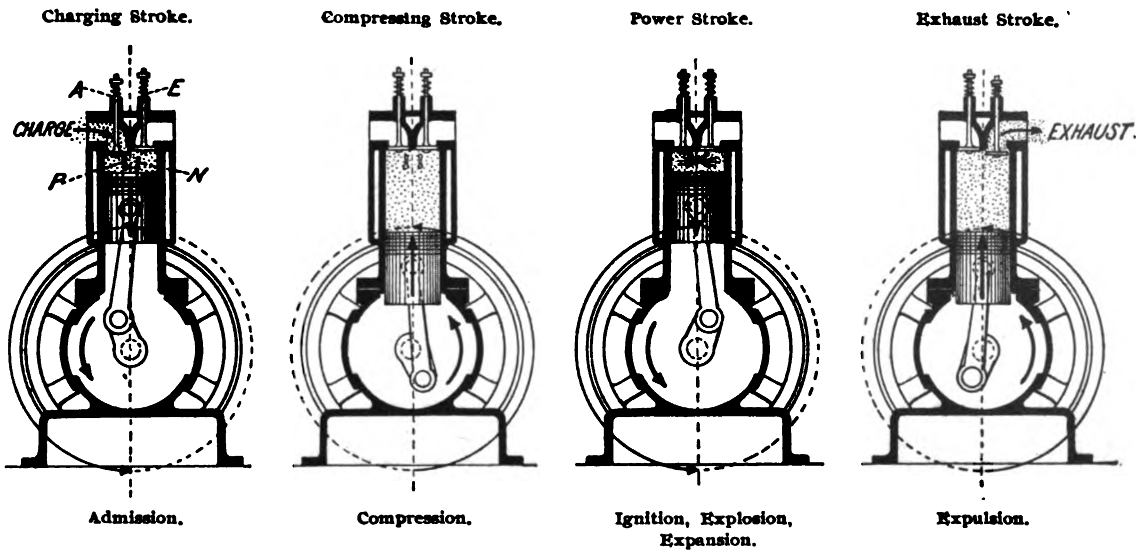

Fig. 10.—SUCCESSIVE STAGES OF THE FOUR-CYCLE METHOD (Paragraph 60)

A, admission valve; E, exhaust valve; N, negative electrode; P, positive electrode of igniter.

the burnt gases are forced into the outer air by way of the exhaust pipe O. The power stored in the fly wheel now pulls the piston downwards on the charging stroke, at the commencement of which, the exhaust valve E is closed by the action of the cam A, and the admission valve J opened by means of the cam B and the lever C, and as the piston travels downward a fresh charge is drawn into the cylinder through the port N of the distribution chamber. When the piston reaches the end of this stroke, the valve J is closed by the action of the cam B, and the continued revolution of the fly wheel pushes the piston upwards on the compression stroke, compressing the entire charge into the clearance space and raising its temperature to the point required for the purpose of ignition. Near the end of the compression stroke a cam on the same shaft which carries B, but situated behind it, makes and breaks an electric circuit at the bottom of the igniter plug F. The resulting spark ignites the compressed charge, and the pressure of the following explosion drives the piston downwards on another power stroke.

It will be observed that one explosion occurs in the cylinder for every two revolutions of the crank, and that of the four strokes of the piston required to complete the cycle only one stroke exerting power is obtained. *Fig.* 10 shows in detail the successive positions of the piston and the relative positions of the crank and the valves during the four parts of the cycle.

The first stage shows the admission valve open, as the descending piston sucks in the charge: in the second, this valve has been closed by the back-pressure from the ascending piston. The third phase illustrates the explosion of the charge, giving impulse to the piston; while the fourth shows the exhaust valve opened, mechanically, just before the completion of the power stroke, to liberate the burnt gases.

61. Two-Cycle Type. Although it is a fact that the four-cycle gas engine has been, up to the present time, the most successful of all internal combustion motors, it is also true that an ideal engine of this class ought to have at least one explosion in the cylinder for every revolution of the crank shaft, or in other words, one power stroke in every two strokes of the piston. The best inventive genius in this line has been exerted for some time in the direction of constructing an engine of this type, that is, one working on a two-stroke cycle, but although some very efficient engines have been produced the effort appears to have been only partially successful. The most notable engine of this type is that of Dugald Clerk. As originally designed it consisted of two cylinders of equal diameter placed side by side, one a power cylinder in which the charge was exploded, the other a charging cylinder which took in the charge and transferred it to the power cylinder under the action of a displacer piston. At one end of the power cylinder the compression space communicated with the charging cylinder by means of a large automatic lift valve which opened into the space, while at the other end V-shaped ports opened into the outer air through the exhaust pipe. The power piston was connected with the main crank of the engine, and the displacer piston to a crank pin attached to one of the arms of the fly wheel. These pistons were so arranged that when the power piston neared its outer limit it over-ran the V-shaped ports and allowed the cylinder to discharge, while the displacer piston always remained in advance of the power crank, in the direction of the motion of the engine, by 90 degrees. The cycle of operations obtained by this arrangement may be described as follows: After the displacer piston has drawn in a charge and moved back a fraction of its return stroke, the power piston uncovers the exhaust ports.

The displacer piston then moves in almost to the end of its cylinder, discharges its contents into the compression space, and forces out at the exhaust ports the burnt gases left by the previous explosion. The return stroke of the power piston then compresses the charge in the power cylinder, ignition takes place, and the piston is moved forwards by the resulting pressure until the opening of the exhaust ports discharges the cylinder and allows the displacer piston to force in a fresh charge. The result is an impulse at every revolution.

62. **New Clerk Cycle Engine.** This engine has lately been modified in such a manner that it is, probably, the most economical gas engine yet produced. According to the new Clerk cycle, after a fresh charge has been transferred from the charging cylinder to the power cylinder, an equal volume of steam, or previously compressed and cooled air, is added to it during the compression stroke, thus doubling the weight of the charge compressed, as compared to that of a four-cycle engine, and resulting in a higher economy in the heating value of the fuel. An efficiency of 44 per cent., probably the very highest that has yet been attained by any engine, is recorded to have been reached by one of these engines working under a compression of about 180 pounds per square inch.

63. **Atkinson Cycle Engine.** Another notable two-cycle engine is the *Cycle* invented by Atkinson in 1885. In this engine the piston makes four strokes, two out and two in, for every explosion in the cylinder, and in this particular it resembles the four-cycle engine; but the piston is coupled to the crank shaft by a linkage or double toggle joint in such a manner that all four strokes are made during one revolution, and furthermore, their lengths are so varied that those for charging and

compression are about one-half the length of the exhaust and power strokes, the two latter travelling the full length of the cylinder. The results obtained by this arrangement are as follows: (1) A power stroke for every revolution of the crank shaft. (2) The expansion of the charge beyond the volume existing before compression. (3) The complete expulsion of the burned gases from the cylinder prior to the admission of a fresh charge.

Over one thousand engines of this type, ranging in size up to 30 B. H. P., were built and sold during the period 1887-1893. They were of ingenious construction, and of unequalled economy of gas consumption; but owing to difficulties experienced with the linkage, and the high piston speed, their construction has been largely superseded by other types. *See paragraph* 217.

This engine, however, served the purpose of demonstrating the practicability of obtaining great economy in gas consumption by expanding the charge to a volume much greater than its bulk previous to compression, and also conclusively proved that the best results in gas engine performance may be obtained when the whole of the burnt gases are expelled from the cylinder prior to the admission of a fresh charge, rather than by retaining a portion of the same within the cylinder for the purposes suggested by some authorities and more fully explained in Chapter X.

64. **Tangye Engine.** The most simple example of the two-cycle method is that of the Tangye engine diagramatically illustrated by *Fig.* 11. Unlike those in the ordinary forms of gas engine, the cylinder is closed at both ends; *Fig.* 11a, shows the piston near the end of the power stroke, it having uncovered

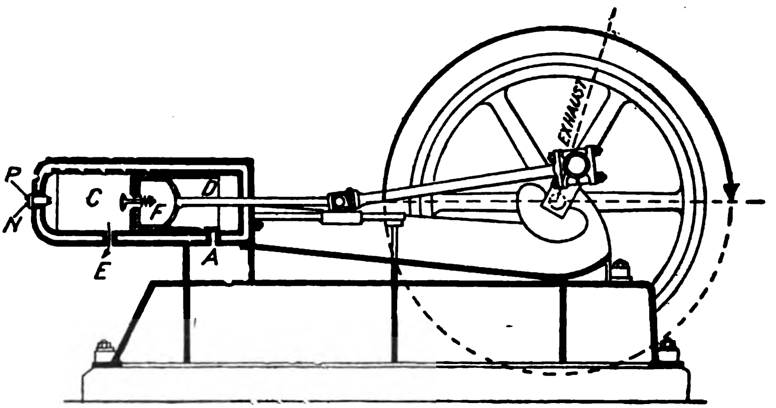

Fig. 11 a.—(Paragraph 64)

Power Stroke of Two-Cycle Method, Showing Exhaust and Admission of Fresh Charge.

A, admission port; C, combustion chamber; D, pre-admission chamber; E, exhaust port; F, valve in piston; N and P, negative and positive electrodes of igniter.

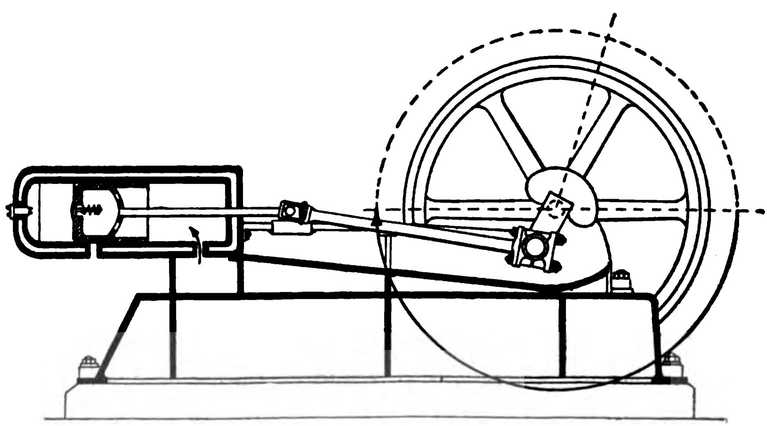

Fig. 11 b.—(Paragraph 64)

Compression Stroke of Two-Cycle Method, Showing Admission to Pre-admission Chamber and Compression in Combustion Chamber.

the exhaust port E, and closed the admission port A. When the piston moves to the end of the stroke the charge pre-admitted into the chamber D, is compressed sufficiently to open the valve F (which automatically closes on the return stroke) and to pass into the chamber C, where it is compressed by the return stroke of the piston and ignited. *Fig.* 11b, shows the piston near the end of the return or compressing stroke, it having closed the exhaust port and uncovered the admission port, thus allowing a fresh charge to enter the pre-admission chamber.

It is perhaps unnecessary to state in this connection, that there is no dearth of designs for two-cycle engines. The necessity for such an engine as the ideal automobile motor is a constant stimulus to the inventive effort directed towards its successful production, and many mechanical arrangements embodying the two-cycle principle are being patented both in the United States and foreign countries at the present time; but, most of them are of an impracticable nature and are therefore very liable to remain undeveloped. A few of these are described in Chapter XVIII.

65. **Diesel Engine.** A type of internal combustion engine, not included in the classification given at the beginning of this chapter is that of Diesel. It is designed to operate on gaseous, liquid, or solid fuel, and to work under a principle which involves the production of the highest temperatures during its cycle of operations by the compression of the air in the working cylinder prior to the introduction of the fuel. The cycle of operations presents an ideal system which may be briefly described as follows: During the first forward stroke of the piston, air alone is admitted to the cylinder at atmospheric pressure and temperature. On the return stroke the piston com-

presses this volume of air to a pressure of about 500 pounds to the square inch, thus raising its temperature to about 1000° Fahr. Then, at this moment, marked by the beginning of the third or power stroke, the fuel is sprayed into the heated air in the cylinder; is ignited instantaneously by the high temperature produced by the previous compression, thus adding heat to the air and increasing its pressure: the resulting expansion drives the piston forward on its power stroke. The combustion is maintained at a constant temperature by the continued spraying of the fuel during the first part of this stroke until sufficient pressure has been developed to overcome the sustained load; the fuel is then cut off by the action of a governor which automatically controls the amount supplied according to the varying load.

Up to the present time, this engine has been principally developed as an oil engine, and is more fully described in Chapter XX. *See paragraph* 239.

66. Six-Cycle or Scavenging Engine. Another type of internal combustion engine not included in the primary classification, is the so-called six-cycle engine. It never attained much practical importance, and is mentioned herein merely to satisfy the curious. It is of the four-cycle type, but in addition to the operations taking place in the latter, a third revolution of the crank shaft or two strokes of the piston are employed to admit a charge of pure air, into the cylinder immediately after the exhaust of the burnt gases, and subsequently expel it. By thus scavenging the combustion space the designers expected to obtain a greater economy of fuel comsumption, but these expectations were never realized and the construction of the type was quickly abandoned.

67. Conditions for Successful Working. The foregoing brief descriptions of the various cycles make it clear that the successful working of an internal combustion engine depends upon six quite distinct but intimately related conditions, which may be briefly stated as follows:

(1) The combining of the fuel and air components of the charge in the proper proportions to give an explosive mixture.

(2) The admission of a full charge into the working cylinder by the charging stroke of the piston.

(3) The application of the proper amount of compression.

(4) The ignition of the compressed charge at the proper moment in the cycle of operations.

(5) The complete combustion of the fuel component, and the utilization of the resulting pressure to the very end of the power stroke of the piston.

(6) The thorough scavenging of the cylinder by completely exhausting the burnt gases therefrom prior to the admission of a fresh charge.

How nearly the foregoing conditions are satisfied in the construction of the most successful engines now in use, will be considered in detail in the next chapter.

CHAPTER V.

GRAPHICS OF THE ACTION OF GASES.

68. The PV-Diagram. How nearly the various types of gas engine approximate to the conditions enumerated at the end of the preceding chapter as essential to the successful operation of a gas engine through the action of their practical working cycles, may be most conveniently ascertained by means of graphical representations of the cycles of their working substances in connection with the cycles of their mechanical arrangements.

Since the work performed by a piston-engine is the product of two factors, the pressure of the working substance multiplied by its increase in volume, it is obvious that if the former be stated in some unit of weight such as pounds, and the latter in a unit of length such as feet, a diagram can be drawn enclosing an area which will represent in foot-pounds the work performed by the engine.

In *Fig.* 12, if the line AB represents pressures in pounds, and the line AC volumes in feet, then for any pressure P required to move a piston from A to a distance corresponding to the volume V, the area of the rectangle APDV will represent the amount of work performed, or

$$\mathbf{PV} = \text{Foot-pounds of work performed.}$$

In this case, the pressure is assumed as constant, and the example illustrates the simplest form of a PV-diagram.

69. Thermal Lines. Usually, however, the pressure is not constant, but decreases as the volume increases, therefore the

line PD will assume the form of the curve PEV, in *Fig.* 13, the varying ordinates of which, *a, b, c,* etc., will represent the pressures for the corresponding volumes, and the area APEV will represent the amount of work performed. A rectangle, whose

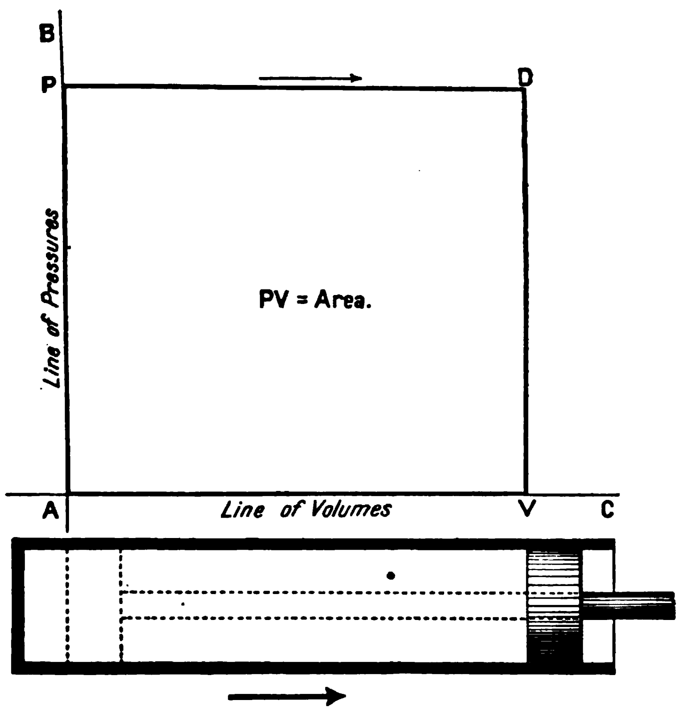

Fig. 12.—Pressure Volume Diagram
(Paragraph 68)

altitude will be equal to the length of the mean ordinate *d,* which represents the mean effective pressure (M. E. P.) of the whole operation, will give an area AFGV, the product of whose base and altitude is equivalent to APEV, or

$$M. E. P. \times V = \text{Foot-pounds of work performed.}$$

In this case, the temperature is assumed as constant, and the curve PEV, represents the expansive action of a gas under that particular condition.

The action of a heat engine is modified by the effects on its working substance of other conditions of temperature, volume, and pressure, which obtain at the time heat is applied. The graphical representations of the thermal lines resulting from those conditions will give areas which will differ, for the various classes of heat engine, according to the method of heat application, and also according to the practical working cycle employed for the various types of any particular class.

70. **Mutual Relations of Temperature, Volume, and Pressure.** In conformity with the laws of permanent gases, the mutual relations of the temperature, volume, and pressure or a gas in the cylinder of an engine vary according to the conditions which obtain at heating.

1. If the temperature of the gas is kept constant, an increase of volume results in a decrease of pressure (Boyle's Law, par. 11).

2. If the pressure of the gas is kept constant, an increase of temperature results in an increase of volume. (Gay-Lussac's Law, par. 12).

3. If the volume of the gas is kept constant an increase of temperature results in an increase of pressure (Gay-Lussac's, Regnault's, and Joule's Laws, pars. 12, 21, 22).

Under these conditions, a gas acts according to the following modes of expansion or compression.

71. **Isothermal Expansion or Compression.** The most natural conditions for the expansion or compression of a gas

doing work in the cylinder of an engine may be stated as follows:

1. For expansion, when the pressure decreases as the volume increases, with a corresponding decrease in temperature due to the external work done by the gas in moving the piston.

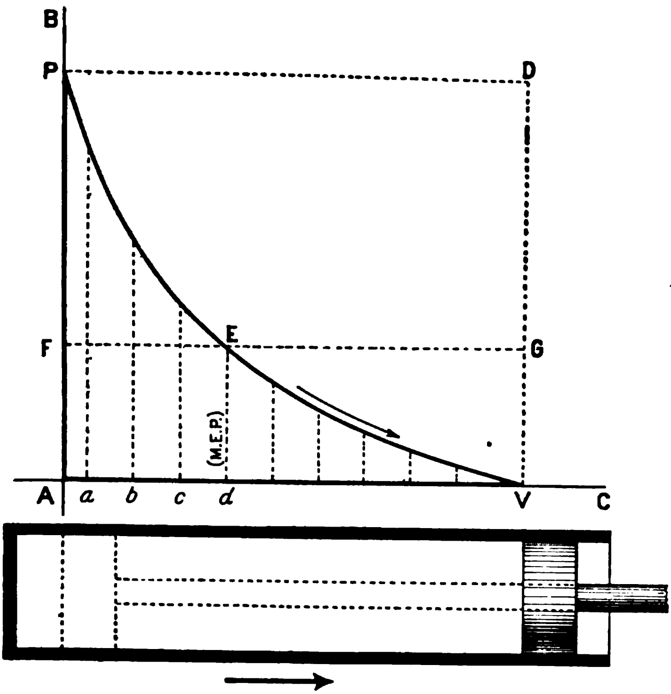

Fig. 18.—Mean Effective Pressure
(Paragraph 69)

2. For compression, when the pressure increases as the volume decreases, with an increase in the temperature due to the work spent upon the gas during the act of compression.

If, however, suitable means are provided, so that during expansion the gas absorbs an amount of heat equal to that expended in moving the piston, and during compression it rejects an amount of heat equal to that which is spent upon it by the act of compression, or in other words, if the temperature of the gas is kept constant its mode of expansion or compression will be *isothermal,* or the temperature of the gas will be the same at all points of the piston stroke, and the volume at any point multiplied by the pressure will be the same or PV=Constant (par. 11), and by assumption—

$$P_1 V_1 = P_2 V_2 .$$

For example—If a given mass of gas having a volume V and pressure P_1 be inclosed in a cylinder and allowed to expand isothermally to volume V_2 and pressure P_2, the graphical representation of the line of expansion will be an equilateral hyperbola BC as shown in Fig. 14, and the work done will be represented by the area ABCD, or

$$V_1 P_1 \text{ hyp. log.} \frac{V_2}{V_1} = \text{Work performed.}$$

It is necessary in order to maintain a constant temperature that the piston must be perfectly free from leakage, and its movement must be regulated to correspond exactly with the rate at which the gas either absorbs or rejects heat. This is clear because if the piston were moved in and out more rapidly than at this rate of speed, the temperature of the gas would be unduly decreased during expansion and increased during compression, and the action of the gas would not be isothermal.

Therefore, isothermal expansion or compression, although an important mode of action in the case of a steam engine, is of very limited significance in the case of a gas engine.

72. Adiabatic Expansion or Compression. When suitable means are not provided for maintaining a constant temperature, or if the action of the gas corresponds to that of a piston moving at a high rate of speed, or if the gas acts within a cylinder which is a perfect non-conductor of heat, then, during expansion the

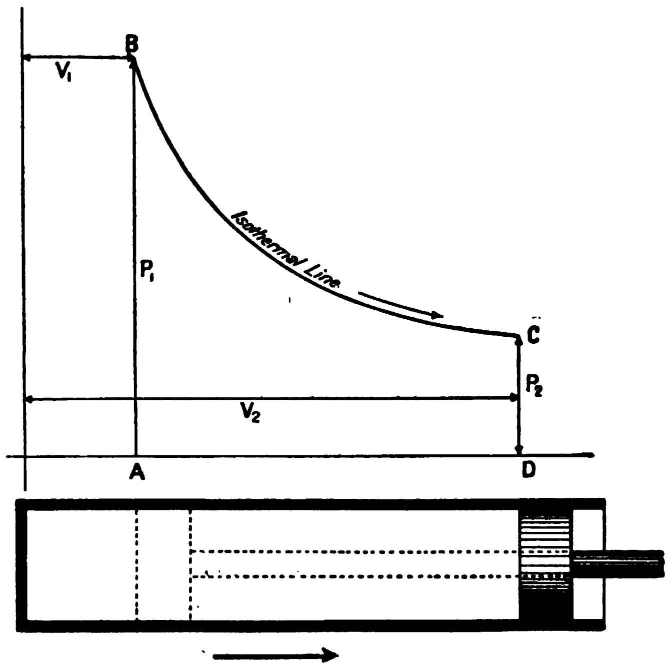

Fig. 14.—Isothermal Line
(Paragraph 71)

temperature will fall by an amount equal to the heat units expended in doing external work, and during compression the temperature will rise by an amount equal to the number of heat units of work spent upon it. This mode of expansion or com-

pression is called *adiabatic* since there is no transfer of heat to or from the gas through the walls of the cylinder, and the external work during expansion is done entirely from the internal energy of the gas.

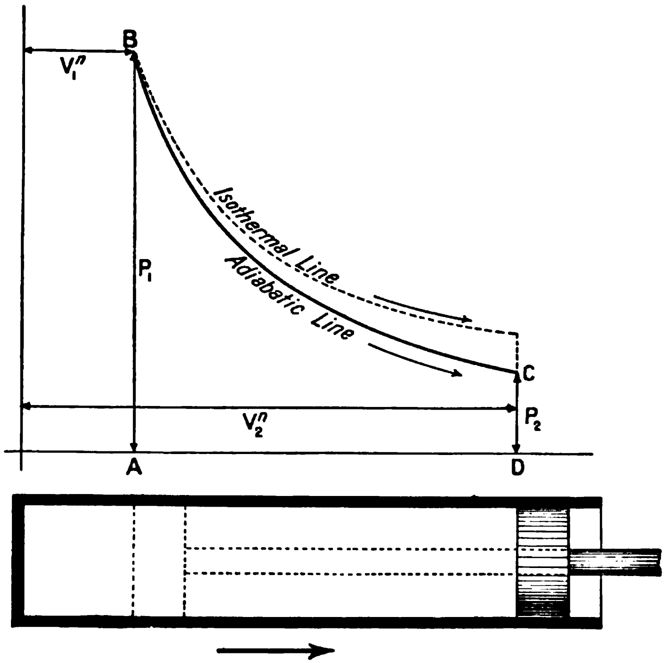

Fig. 15.—Adiabatic Line
(Paragraph 72)

It is obvious, that adiabatic action must be accompanied by a change in the ratio of pressure to volume, therefore, at the end of the piston stroke the pressure will be less than in the case of isothermal expansion by an amount corresponding to the heat expended in doing external work.

In *Fig.* 15, the curve of adiabatic expansion is shown by the line BC.

In isothermal action **PV** = Constant, therefore, in order to express the law of adiabatic action it is necessary that the

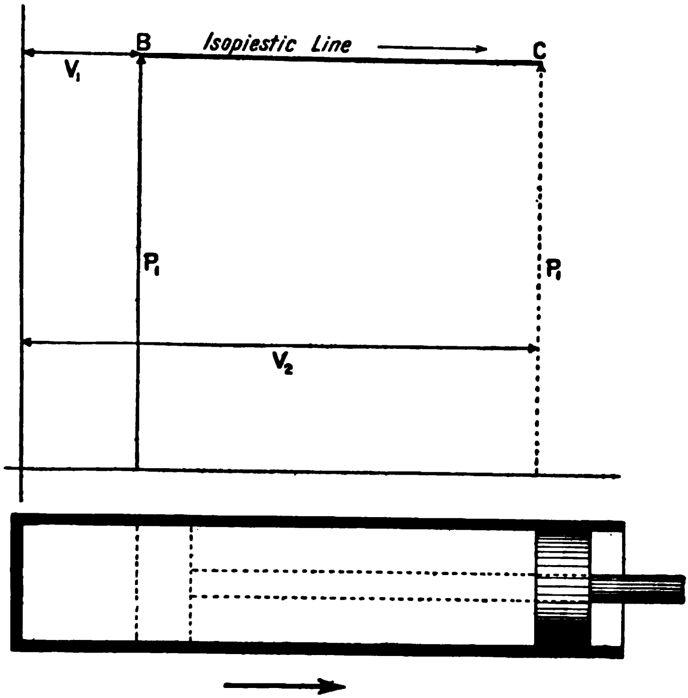

Fig. 16.—Isopiestic Line or Isobar.
(Paragraph 73)

factor **V** be given an exponent greater than unity, and if n be put to represent this exponent, then $\mathbf{PV^n}$ = Constant.

It can be shown, however, that n is equal to the ratio—Specific heat at constant pressure ÷ Specific heat at constant volume, or

$$\frac{C_p}{C_v} = y \quad \text{(par. 23).}$$

Therefore, the law of adiabatic action is $PV^y =$ Constant, and by assumption

$$P_1 V_1^y = P_2 V_2^y,$$

and

$$\frac{P_1 V_1 (1 - r^{1-y})}{y - 1} = \text{Work performed},$$

where r is the ratio $V_2 \div V_1$, or the ratio of expansion.

Another form of the expression for the work performed is

$$\frac{P_1 V_1 - P_2 V_2}{y - 1} = W$$

According to Boyle's and Gay-Lussac's laws combined (par. 17),

$$P_1 V_1 : P_2 V_2 : : T_1 : T_2,$$

or

$$\frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2}$$

Therefore to ascertain the change in the temperature of a gas when expanded or compressed adiabatically, it is necessary to combine the expressions—

$$P_1 V_1^y = P_2 V_2^y \qquad \text{and} \qquad \frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2},$$

which gives $T_1 \left(\frac{V_1}{V_2}\right)^{y-1} = T_2$,

73. **Isopiestic Lines or Isobars.** It will be noted, that according to the conditions of heating given in paragraph 70, the isothermal and adiabatic lines are not the only thermal lines which may be graphically represented on the PV-diagram. For example, if a given quantity of gas be placed in a cylinder and allowed to expand under the influence of heat, or if its volume be increased in any other manner, while its pressure is kept constant, its expansion will be represented by a horizontal line

parallel to the Line of Volumes, and will lie above the latter at a height proportional to the constant pressure maintained above it. Such a line is called an *isopiestic line* or *isobar,* and corresponds to BC in *Fig.* 16.

Isopiestic expansion occurs during the charging stroke of the piston of a gas engine, when the charge is drawn into the cylinder, and isopiestic compression occurs during the exhaust stroke, when the burnt gases are being expelled from the cylinder, provided that in both cases the area of the valves is sufficient to prevent variations of pressure during the operations which change the volume of the gas.

74. **Isometric Lines.** On the other hand, suppose a given mass of gas to be placed in a cylinder and heated while its volume is kept constant; then, the addition of heat will cause an increase of pressure, and the line traced on the PV-diagram will be vertical, and will lie parallel to the Line of Pressures at a distance proportional to the space occupied by the original volume of the gas as shown by the line AB in *Fig.* 17.

Such a line is called an *isometric line,* and represents the condition when the charge in the cylinder of a gas engine is ignited while the piston *stands* at its inner dead center.

75. **Thermal Lines of Heat Engine Cycles.** Relative to the horizontal and vertical thermal lines it will be observed, that in the case of isothermal expansion or compression, if the temperature and pressure remain constant while the volume increases, the line traced on the PV-diagram will be a horizontal one, and if the temperature and volume remain constant while the pressure increases, the line traced will be vertical. Therefore, similar lines on the diagram may represent dissimi-

lar modes of action, and in the interpretation of diagrams care should be taken to always keep in view the method of heating, and the conditions of temperature, volume, and pressure which obtain at that period. (par. 70).

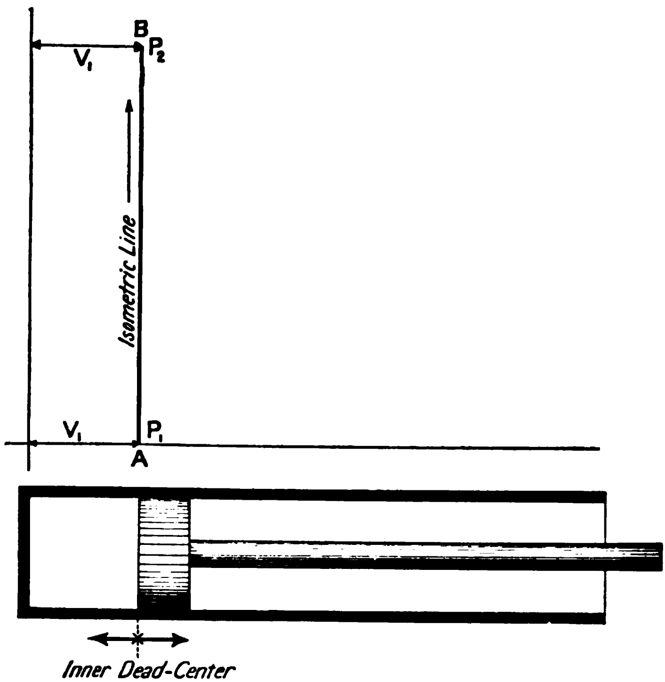

Fig. 17.—Isometric Line
(Paragraph 74)

It may be stated, however, that usually, horizontal and vertical lines indicate isothermal action in the case of a steam engine, and isopiestic or isometric action in that of a gas engine.

Furthermore, a little study of the thermal lines described in the preceding paragraphs will serve to indicate, that if neither

the temperature, the volume, nor the pressure, remain constant during expansion or compression it will still be possible to determine, by experiment, various straight lines or curves which will represent on the PV-diagram variations of pressure and volume that do not conform to any law capable of graphical representation or calculation in advance.

In fact, the majority, if not all, of the thermal lines traced on indicator diagrams, actual PV-diagrams, are more or less of this character on account of the impossibility of maintaining under actual working conditions the absolute assumptions which form the basis of all theoretical considerations.

CHAPTER VI.

INDICATOR DIAGRAMS OF ENGINE CYCLES.

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76. **Carnot's Cycle or Cycle of Ideal Heat Engine.** As no thorough understanding of the action of heat engines in general, and of those using a gas for a working substance in particular, can be reached without a knowledge of the cycle of action of the ideal heat engine, as described by Carnot, this cycle will now be explained as follows:

Referring to *Fig.* 18, which shows the thermal lines of the cycle on the plane of the PV-diagram, imagine a cylinder made of non-conducting material—with the exception of its bottom which is a perfect conductor of heat—and having a piston, also made of non-conducting material, working within it. Imagine also, an inexhaustible source of heat **A** having a constant temperature T_1, a non-conducting cover **B**, and a cold body **C** having a constant temperature T_2 lower than T_1 which is capable of receiving or absorbing an indefinite amount of heat.

Let the cylinder contain one pound of a perfect gas at a temperature T_1, volume V_a, and pressure P_a corresponding to the point **a** on the diagram. The cycle of action will be the result of four operations as follows:

1. If **A** be applied to the bottom of the cylinder and the piston allowed to move, the gas will expand isothermally at a temterature T_1 taking heat from **A** and pushing the piston forward to **b**, and the pressure will change to P_b and the volume to V_b.

2. Now, if **A** be removed and **B** applied to the bottom of the cylinder, the gas will expand adiabatically, continuing to push

the piston forward at the expense of its own internal energy, and its temperature will fall. Allow the gas to expand until its temperature falls to T_2. Then, the pressure will have fallen to P_c and the volume increased to V_c.

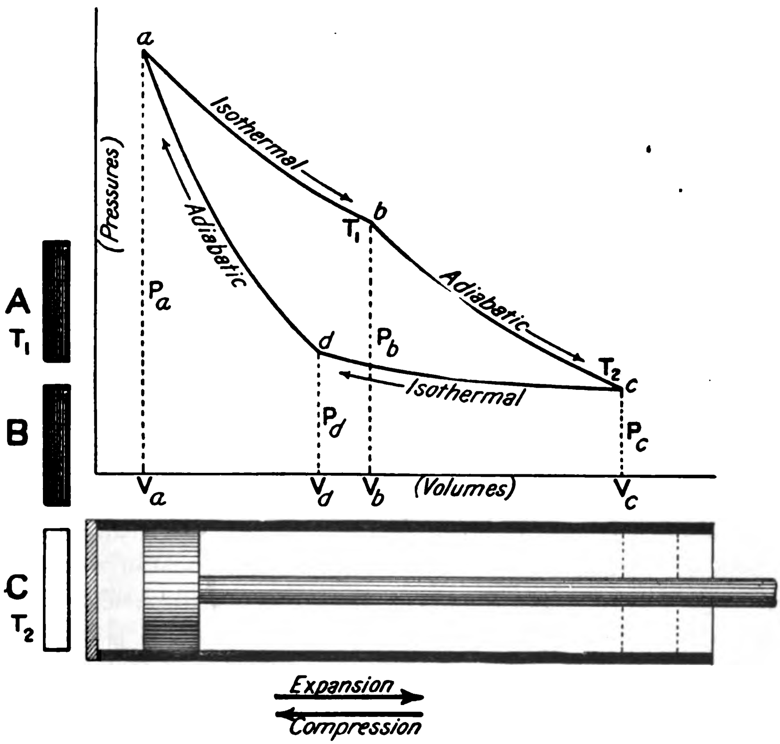


Fig. 18.—Carnot's Cycle (Paragraph 76)

3. Now, remove B and apply C to the bottom of the cylinder and force the piston backwards. The gas will be compressed isothermally at a temperature T_2, rejecting into C all the heat due to the work spent upon it by the act of compression. Con-

tinue the compression until a point **d** is reached from which a line of adiabatic compression will pass through the point **a**.

4. If **C** be now removed and **B** again applied to the bottom of the cylinder, the gas will continue its compression adiabatically, the pressure and temperature rising, and, if the point **d** be properly chosen, the cycle will be completed by the restoration of the original temperature T_1 and the original pressure P_a when the piston reaches the point corresponding to the original volume V_a.

The equations for determining the proper positions of **b** and **d** for the relations of V_b and V_c required to give the final temperature T_2 are, according to paragraph 72, as follows:

$$\frac{T_1}{T_2}=\left(\frac{V_c}{V_b}\right)^{\gamma-1} \text{ for b,}$$

and

$$\frac{T_1}{T_2}=\left(\frac{V_d}{V_a}\right)^{\gamma-1} \text{ for d.}$$

Hence $\frac{V_c}{V_b}=\frac{V_d}{V_a}$, and $\frac{V_b}{V_a}=\frac{V_c}{V_d}$,

or the ratio of isothermal expansion is equal to the ratio of isothermal compression. It will be noted, that the heating is at constant temperature (par. 70) and that the cycle of action of the gas includes only the isothermal and adiabatic modes of expansion or compression. Therefore, if the ratios last stated be denoted by **r**, then according to the first law of thermodynamics (paragraphs 22, 23, 26) the net external work done by the gas is—

$$d\ (T_1 - T_2) \text{ hyp. log. } r,$$

and the thermal efficiency of the engine is

$$\frac{d\ (T_1 - T_2) \text{ hyp. log. } r}{d\ T_1 \text{ hyp. log. } r} = \frac{T_1 - T_2}{T_1}. \quad \text{(par. 36)}$$

On the diagram, the area V_a **a b c** V_c, represents the work done by the gas during expansion, and the area V_a **a d c** V_c, the work spent upon the gas during compression. Therefore, the area **a b c d** represents the net external work done by the gas during the entire cycle.

77. Indicator Diagram. Since a thermal line is the resultant of two motions, one acting vertically and representing the variations in the pressure of the gas, the other acting horizontally and representing variations in the volume corresponding to the position of the piston at different points of its stroke, the drawing of an actual PV-diagram or *indicator diagram* of the practical working cycle of an engine is accomplished by means of a mechanical device commonly known as an *indicator*.

The general principle upon which all forms of indicators operate may be briefly described as follows:

78. Working Principle of Indicator. In *Fig.* 19, A represents a small cylinder screwed into the side of the engine cylinder and opening into the clearance space B. C is a piston working within A against the pressure of the gas in B by means of the tension of the spring D. E is a horizontal arm attached to the rod of the piston C and carrying on its outer end a pencil point F. G is a carrier bar upon which a board H carrying a sheet of paper is moved back and forth in a direction opposite to that of the piston of the engine, by means of the spring L and the lever M, the upper end of the latter being attached by a cord to the movable board, and the lower end to some part of the piston rod such as the crosshead N.

Assume that the piston K is at its inner dead center *o*, and that the clearance space B is empty. The piston C will be

down and the pencil point will be at F. Now, if steam be admitted to B, the increasing pressure will drive the piston C upwards, carrying the pencil vertically from F to *r* until the pressure in the clearance space is sufficient to move the piston. If this pressure be kept constant while the piston travels from *o* to *p*, and moves the board H through a corresponding distance from *o'* to *p'*, the pencil will trace the line *r x*. But ordinarily, the pressure is not kept constant, the supply of steam

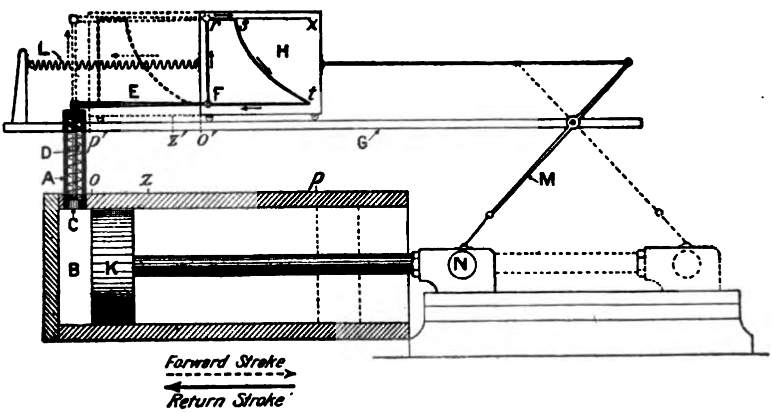


Fig. 19.—Working Principle of Indicator
(Paragraph 78)

being stopped when the piston has travelled some part of its forward stroke. Assume that the supply of steam is stopped when the piston has travelled a distance equal to one-quarter the length of its full stroke or to *z*. The movement of the piston from *o* to *z* will carry the board from *o'* to *z'*, and as the pressure is kept constant up to this point, the pencil will trace a horizontal line from *r* to *s*, the cut-off point. The continued advance of the piston will move the board towards *p'* and as it

will also increase the volume of the steam, the pressure in the engine cylinder will fall, thus relieving the compression on the spring D and allowing the piston C to descend. As the result of these operations and movements, the indicator pencil will trace the line *s t*, the point *t* coinciding with the point F on the diagram when the piston is at its outer dead-center *p*, and the board at the limit of its backward movement *p'*.

Now suppose that the steam is suddenly and completely exhausted from the engine cylinder. Driven by the stored-up energy in the fly wheel, the engine piston will travel from *p* to *o* on its return stroke, pulling the board from *p'* to *o'*, and as no pressure exists in the cylinder the indicator piston will remain down, and the indicator pencil will trace the line *t* F, and thus complete the area which graphically represents on the indicator diagram the practical working cycle of the engine.

79. **Indicators.** In actual indicators, the pencil arm E, referred to in the preceding paragraph, instead of being attached in a fixed horizontal position to the upper end of the rod of the indicator piston is replaced by a system of levers which multiplies the motion of the piston, thus permitting the use of indicator cylinders whose pistons have a smaller range of motion. Also, the movable board H is replaced by a rotatable drum which carries the paper. A spiral spring in the interior of the drum rotates it in a direction opposite to that of the forward stroke of the engine piston, the spring being put into a state of tension, when the drum is rotated in the opposite direction, by means of a cord attached to the engine piston, during the return stroke of the latter.

These substitutions allow very compact and efficient mechanical arrangements. Detailed descriptions of those suitable for

use in connection with gas engines, together with instructions relative to the manner in which they are attached to the engine in taking diagrams, will be found in Chapter XXIII.

80. Theoretical Indicator Diagram of Steam Engine Cycle. The following analyses of the theoretical and actual indicator diagrams of a high pressure, non-condensing, single-acting steam engine are here introduced as a necessary step towards the consideration of the more complex diagrams which result from the operation of the various gas engine cycles.

In *Fig.* 20, the area *a b c d f,* inclosed by thin lines, represents the theoretical diagram. On the assumption that the steam is admitted uniformly at maximum boiler pressure, 180 pounds absolute, *a b* is the *admission line,* the steam expanding isothermally; *b* the *point of cut-off* at one-quarter stroke; *b c* the *line of adiabatic expansion; c* the *point of release,* or the point at which the exhaust valve opens; *c d f* the *exhaust line.* The line *c d* forms a portion of both the expansion and the exhaust lines. From *c* to *d* the steam expands adiabatically, falling in temperature and pressure to the pressure of the atmosphere, and, since it is assumed that the exhaust valve remains open during the whole of the return stroke of the piston, the line *d f* represents an *isopiestic line,* the steam being neither expanded nor compressed, but simply expelled from the cylinder at the constant pressure of the atmosphere.

Referring to paragraph 76, it will be noted that the point **b** on the diagram of Carnot's cycle corresponds to the point of cut-off in the theoretical diagram of the steam engine, but it is evident, that owing to the exhaust of the steam at the end of the forward stroke of the piston, and the keeping open of the exhaust valve up to the end of the return stroke, the point **d** of

Carnot's cycle has no significance in this particular case of the steam engine. Furthermore, owing to the consequent inability to perform the third and fourth operations of the ideal cycle, the theoretical cycle, just described, represents an incomplete cycle, or that of a non-reversible engine.

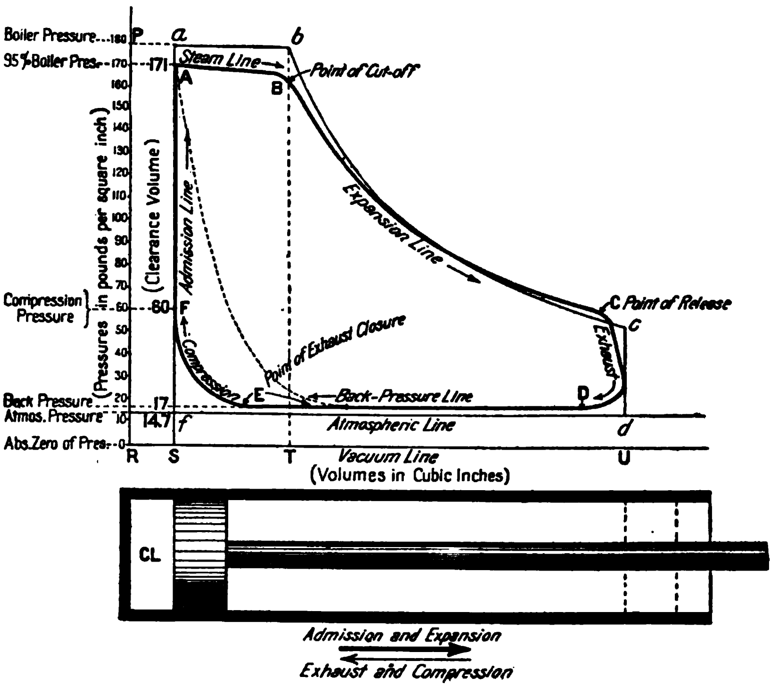


Fig. 20.—Theoretical Diagram of Steam Engine
(Paragraphs 80-83)

It will be shown immediately, however, that the point E on the actual diagram of a steam engine, corresponding to the point d of that of the ideal engine is of great significance in actual practice.

81. Actual Indicator Diagram of Steam Engine. In *Fig.* 20, the area A B C D E F, inclosed by heavy lines, represents the actual indicator diagram corresponding to the theoretical diagram considered in the preceding paragraph.

It will be observed that the area of the actual diagram is smaller than that of the theoretical diagram. This reduction is due to the difference between actual working conditions and theoretical assumptions.

Under actual working conditions, on account of the resistance of the ports and passages, the pressure within the cylinder is less than the maximum boiler pressure during admission, and greater than the atmospheric pressure during exhaust.

During admission, the pressure in the cylinder ranges from 90 to 95 per cent. of maximum boiler pressure, and decreases as the piston advances, the increasing speed of the piston requiring an increasing amount of steam to maintain a constant pressure.

When the admission ports and passages offer much resistance, the steam is throttled or *wire-drawn,* the expansion being imperfectly resisted, which causes the line of admission to lie below the line of maximum boiler pressure, and to slope downwards as shown by the line AB, which is a line of *isothermal* expansion and commonly known as the *steam line.*

For similar reasons, during exhaust, the actual *back-pressure* exceeds the atmospheric pressure by an amount which depends upon the freedom with which the steam escapes from the cylinder. In non-condensing engines, the actual back pressure ranges from 16 to 18 pounds absolute, and causes the exhaust line to lie above the atmospheric line.

Furthermore, as an effect of wire-drawing, both the admission and exhaust valves open and close more or less slowly, so that the cut-off and release are not instantaneous, the diagram consequently having rounded corners at B and C, instead of the sharp corners at *b* and *c* of the theoretical diagram.

Since the sharpness of the cut-off and release depends to a great extent upon the kind of valves and valve gear used, the release is usually allowed to occur a little before the end of the forward stroke, and the line of expansion during exhaust takes the form of the loop CD, indicating that the pressure continues to fall during a part of the return stroke until it is equal to the back-pressure.

A further consideration of the actual diagram, or the analysis of that part of the cycle represented by the line DEF, involves the consideration of the matter of *clearance*.

82. Clearance. In all actual engines, a small space CL, is left between the cylinder cover and the piston when the latter stands on its inner dead-center. This space is called the *clearance*, and since it constitutes a volume not swept by the piston, it is evident that it must necessarily be filled with unexhausted steam when admission occurs. Therefore, the steam in the clearance forms a portion of the whole steam which expands after the supply from the boiler is cut off.

In *Fig.* 20, if SU be the cylinder volume swept by the piston, RS the clearance volume, and ST the cylinder volume swept by the piston during admission or up to the point of cut-off, the apparent ratio of expansion is SU ÷ ST; but the actual ratio is

$$\frac{RS + SU}{RS + ST},$$

and it is evident, that clearance must be taken into consideration in calculations relative to curves of expansion, and in the analysis of curves of compression.

In the case of actual indicator diagrams it is conveniently allowed for by placing the *clearance line* back from the line of no volume at a distance corresponding to the clearance. In *Fig.* 20, RP is the line of no volume, S*a* is the clearance line, and the distance RS is equal to—

$$\frac{RS}{SU} = \frac{\textit{Clearance Volume}}{\textit{Piston Displacement Volume}}$$

83. Effect of Clearance in Steam Engine. The effect of clearance on the thermodynamic efficiency of a steam engine depends materially on the compression, which alters the consumption of steam per piston stroke.

Referring to the line DEF in *Fig.* 20, it is clear that so long as the exhaust valve remains open, the steam will be expelled from the cylinder isopiestically at the constant pressure due to wire-drawing; but if the exhaust valve is closed before the end of the return stroke, the steam remaining in the cylinder will be compressed adiabatically into the clearance space, its temperature and pressure being increased according to the amount of the compression pressure corresponding to the ratio of compression.

Therefore, by properly selecting the *point of exhaust closure* E, the pressure of the steam in the clearance may be made to rise up to the pressure at which the steam is admitted, as shown by the dotted line EA. In such a case, the compression will be complete and it will have no direct effect on the consumption of steam, or on the efficiency. But if the compression is incomplete, or if there is no compression, the opening

of the admission valve will cause an inrush of steam and result in an increased consumption thereof which is only partially counterbalanced by the increased area of the diagram, so that the net result will be a reduced efficiency.

In *Fig.* 20, the location of the point E gives a pressure of 60 pounds absolute to the steam in the clearance space, and if the admission phase of the cycle be considered in connection with this pressure and the clearance volume, it will be seen that since the steam is admitted at a pressure of 180 pounds while the piston is moving forward slowly, the clearance space will be filled quickly, and the rapid increase of pressure from 60 to 171 pounds will give a vertical admission line FA. The area of the diagram with a compression pressure of 60 pounds is unquestionably greater than that of the diagram in which the pressure is carried up to 171 pounds, but as already stated, the increase in the area of the former only partially counterbalances the increased consumption of steam due to the required increase of the pressure of the steam in the clearance from 60 to 171 pounds.

Owing to mechanical difficulties, the attainment of complete compression is impossible, and since incomplete compression signifies a reduced efficiency, the principal value of compression in the case of a steam engine is in connection with the mechanism and not with the working substance. In other words, it provides a cushion of steam which prevents the shock incident to the admission of high pressure steam into a comparatively empty clearance, and it also imposes a certain amount of work on the piston while the velocity of the latter is being rapidly reduced, thus preventing the development of those strains which are due to the inertia of the reciprocating parts of the engine.

84. Theoretical Indicator Diagram of Gas Engine Cycle. In the case of a steam engine, the cycle of the working substance is completed during two strokes of the piston. This cycle consists of four phases or parts which occur in the following order, admission, expansion, exhaust, and compression: the admission and expansion taking place during the forward or power stroke, and the exhaust and compression during the return stroke. Owing to the method of heating, which is external combustion at constant temperature, this cycle cannot be materially modified in the various types of steam engine.

This statement should be regarded as applying to piston engines only, the steam turbine operating upon a distinct cycle of its own, which may be termed *isopleric,* or a cycle of constant volume. Work is performed by abstraction of the energy of velocity rather than by expansion accompanied by transference of the energy of pressure.

In the case of the gas engine, however, the internal combustion method of heat application, permits of heating at constant temperature, volume, or pressure, and the cycle of the working substance may be completed during either two or four strokes of the piston according to the type of engine as described in Chapter IV.

Since the four-cycle engine represents the most successful type of gas engine developed up to the present time, a consideration of its indicator diagram will be amply sufficient to ascertain the general characteristics of gas engine cycles.

In the four-cycle engine, the cycle of the working substance consists of four parts which occur in the following order during four strokes of the piston—admission during the first forward stroke, compression during the following return stroke, expansion during the second forward or power stroke, and exhaust during the second return or exhaust stroke (par. 60).

Fig. 21, shows the theoretical diagram of a four-cycle gas engine heating at constant volume. The assumed values for temperature, volume, and pressure, however, do not correspond to the maxima and minima of such as may be derived from

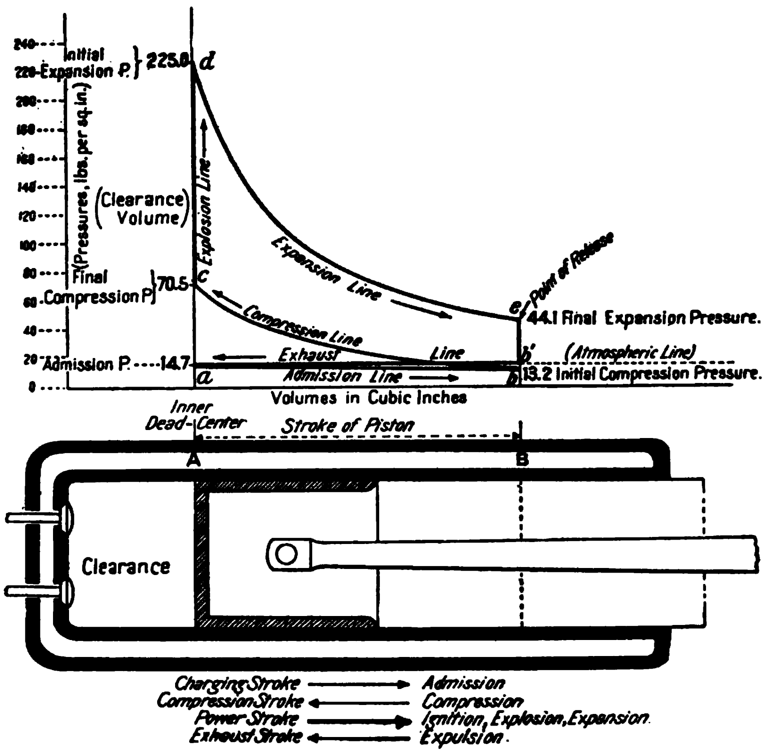


Fig. 21.—Theoretical Indicator Diagram of Gas Engine
(Paragraphs 84-85)

theoretical computations, but represent values which are a fair average of those occurring in the cylinder of a gas engine operating under actual working conditions.

The manner in which this diagram is built up by the action of the practical working cycle of the engine, and the special phenomena such as ignition, explosion, etc., which occur during the various parts of the cycle, will be found considered in detail in the next chapter.

In all hypothetical considerations of the action of any heat engine, similar modifications of purely theoretical assumptions are necessary; this is true, also, with regard to the investigation of air or ammonia compressors, which may be held as reversed-cycle heat engines. The observation of these variations from the ideal or a calculated normal, the determination of their causes, together with an assignment of their probable values, constitute a working theory of each particular machine, upon which designers may rely. Such a theory, founded upon observation and experiment, is only to be deduced from long-continued tests carried out by many persons, with painstaking care, and under all conceivable conditions.

CHAPTER VII.

INDICATOR DIAGRAMS OF GAS ENGINES.

85. Classes of Indicator Diagrams. As stated in paragraph 70, the cycle of the working substance of a gas engine varies according to the conditions of temperature, volume, and pressure which obtain at heating. Therefore, the indicator diagrams of the various types of gas engines may be conveniently divided into three definite classes as follows:

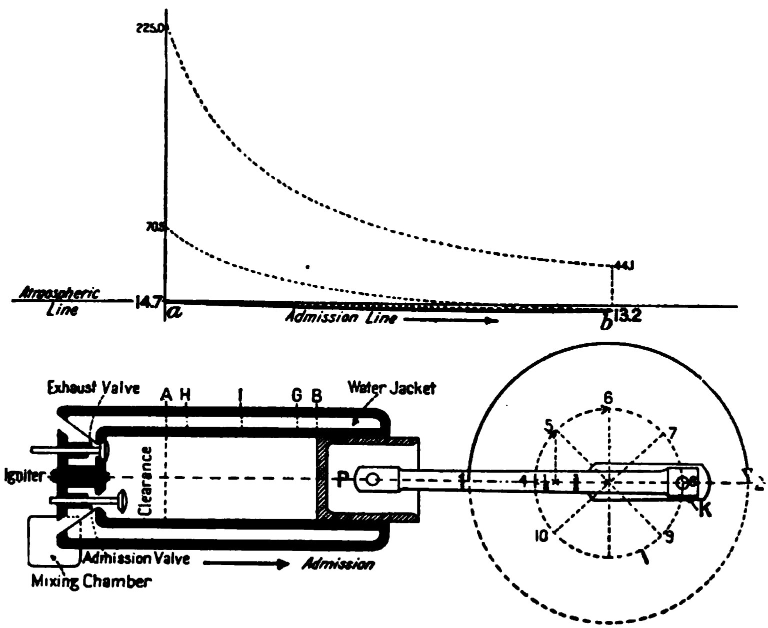
1. Those of engines heating at constant temperature.
2. Those of engines heating at constant volume.
3. Those of engines heating at constant pressure.

Referring to *Fig.* 21, paragraph 84, it will be noted that the cycle of a gas engine includes two definite groups of both initial and final temperatures, volumes, and pressures in addition to those of admission and exhaust. For convenience these two groups may be defined as follows:

1. Initial and final compression temperature, volume, and pressure.
2. Initial and final expansion temperature, volume, and pressure.

The relation of these groups to each other and to the efficiency of the engine may be best understood by developing or building-up the indicator diagram of a gas engine heating at constant volume, and studying each successive phase thereof in connection with the relation of the motion of the crank to that of the piston.

86. Relation of Crank Motion to Piston Speed. Referring to *Fig.* 22, it will be observed, that while a crank K, revolving at uniform speed, travels from 4 to 5, or through one-eighth the circumference of the crank-circle, the attached pis-



Charging Stroke

Fig. 22.—Indicator Diagram of Engine; Heating at Constant Volume. (Paragraphs 86, 87, 88)

ton P will move forward from A to H, or through one-eighth of its stroke; but while the crank passes from 5 to 6, a distance also equal to one-eighth of the circumference of the crank-circle, the piston will move from H to I, or three-eighths of its stroke. In other words, the uniform rotary motion of

the crank causes great variations in the speed of the piston at different points of its stroke, the speed of the piston being more rapid while the crank passes from 5 to 7, and from 9 to 10, than while it passes from 10 to 5, and from 7 to 9.

Yet, it will be observed, that on account of the very nature of the cause, these variations are themselves of a uniform character and constitute the connecting link between the cycle of the working substance and the cycle of the machine (paragraphs 40-46).

For example, the action of a gas engine heating at constant volume depends absolutely on the relative conditions of temperature, volume, and pressure, brought about by the slow movement of the piston while the crank passes from 10 to 5, or over its inner dead center.

We are now in a position to consider the sucessive phases of the cycle of a gas engine heating at constant volume.

87. Indicator Diagram of Engine Heating at Constant Volume. *Figs.* 22, 23, 24 and 25, illustrate the four phases of this cycle. The dotted lines correspond to those of the theoretical diagram given in *Fig.* 21, paragraph 84, and serve as a basis for comparison. It is evident, that since one or more phenomena occur during each phase of the cycle, it is quite difficult to designate each phase by a single expression which shall be significant of all the phenomena occurring in that phase, therefore, the most convenient method is to base the consideration upon what occurs during each of the four strokes of the piston, which constitute the cycle of the machine.

88. Charging Stroke. Referring to *Fig.* 22, during the charging stroke, the piston moves from A to B, the crank from 1 to 2, and the indicator pencil traces the admsision line *ab*.

Usually the fresh charge is admitted at atmospheric pressure and temperature, but while it is being drawn in, it becomes heated by the burnt gases left over from the previous combustion, and also by contact with the hot walls of the cylinder. The temperature of the burnt gases may be as high as 1000° Fahr., but it is impossible to determine accurately just how much heat is thus added to the fresh charge, therefore, the initial compression temperature becomes a matter of assumption in gas engine calculations. Usually, and in the absence of a temperature diagram, the initial compression temperature is assumed to be slightly above that of the issuing jacket-water and ranges from 150° to 200° Fahr. It will be understood in this connection, that in the case of a gas engine, the jacket is used for an entirely different purpose to that which is the case with a steam engine. In the latter, the temperature of the working substance is comparatively low, and requires to be kept constant. This is accomplished by placing a jacket of non-conducting material around the cylinder to keep in the heat; while in the case of the former, the temperatures occurring within the cylinder, through the combustion of the highly inflammable gases therein, are so high, that a jacket of circulating water is placed around the cylinder for the purpose of carrying off a portion of the heat (par. 140). Under these circumstances, an initial compression temperature of 170° Fahr., represents a fair average for an ordinary or non-scavenging engine, and 150° Fahr., that of a scavenging engine.

Another condition which affects the charge during admission is the reduction of pressure due to wire-drawing. This causes the pressure to drop below that of the atmosphere, so that the admission line usually forms a loop below the atmospheric line. In actual practice, the drop of pressure due

to this cause ranges from ¼ to 1¾ pounds, about 1½ being a fair average. This gives a normal initial compression pressure of 13.2 pounds per square inch.

89. Compression Stroke. Referring to *Fig.* 23: At the end of the charging stroke, the admission valve closes, the en-

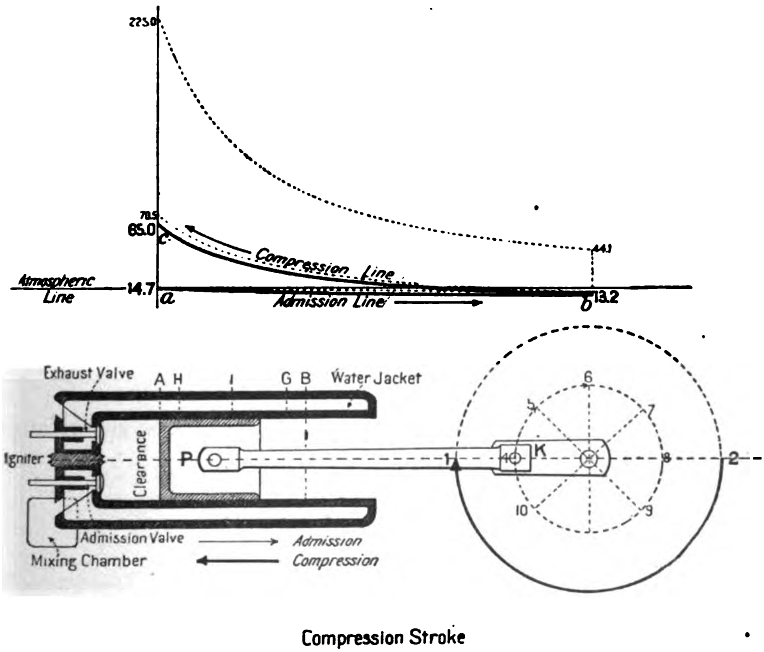


Fig. 23.—Indicator Diagram of Engine; Heating at Constant Volume. (Paragraph 89)

ergy of the fly-wheel moves the crank from 2 to 1 and the piston being driven backwards from B to A, compresses the charge into the clearance space, thus raising both the temperature and the pressure of the latter,

If the cylinder walls were made of non-conducting material the charge would be compressed adiabatically, and its final compression temperature and pressure could be determined accurately by the formulae given in paragraph 72; but, since the engine would not continue to run longer than a few minutes under such conditions, it is apparent that, in actual practice, the charge will be compressed in conformity with no known law, and therefore, its temperature and pressure after compression may be ascertained only by the application of some form of approximate formulae based upon data derived from actual indicator diagrams.

A careful study of a large number of such diagrams indicates the following named properties and conditions, considered in connection with the action of the machine, as the principal factors which affect the final compression temperature and pressure of the charge.

1. The dilution of the charge or the proportion of gas to air.

2. The quantity and character of the burnt gases remaining in the clearance after exhaust.

3. The specific heat of the charge.

4. The ratio of compression.

5. The piston speed.

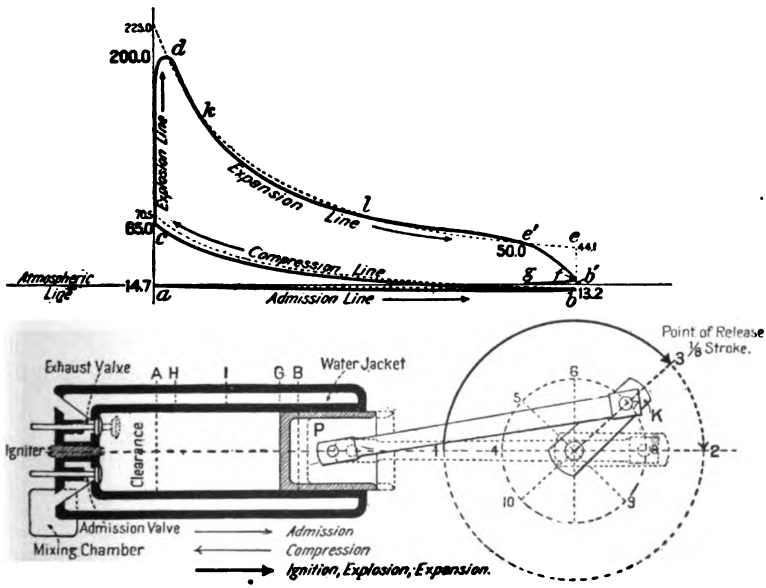
6. The temperature of the jacket-water.

Since the combined effect of these factors is the matter for immediate consideration, their individual effect will be found more fully treated in Chapter X.

The combined effect of these factors may cause the indicator pencil to trace the compression line *bc*, either above or below the calculated normal. In the present case it lies below the normal, the indicated final compression pressure being 65

pounds, corresponding to a calculated final compression temperature of about 400° Fahr.

The probable cause or causes of this variation from the theoretical normal will be found properly explained in Chapter X.



Power Stroke.

Fig. 24.—Indicator Diagram of Engine; Heating at Constant Volume.
(Paragraph 90)

90. Power Stroke. Referring to *Fig.* 24: near the end of the compression stroke, the charge is ignited, and the heat evolved by the combustion of the fuel gas increases the temperature and pressure of the charge in the cylinder. Since these phenomena occur while the crank is passing over its inner

dead center 4, and through the arc of the crank-circle from 4 to 5, during which the forward movement of the piston is very slow, the volume of the charge is kept practically constant while its temperature and pressure are rapidly increased, and cause the indicator pencil to trace the explosion line *cd*. The position of the point *d*, which corresponds to the maximum pressure of the cycle or the initial expansion pressure, depends upon the following conditions:

1. The explosion temperature of the charge due to the calorific value of the fuel gas and the rate of inflammation of the mixture.

2. The point of ignition, or the point in the revolution of the crank relatively to its inner dead center 4, at which the charge is ignited.

3. The piston speed, or the number of revolutions of the crank per minute.

The individual effect of these conditions will be found fully considered in Chapter X.

In the present case, the position of the point *d* indicates that the combustion was practically instantaneous or explosive, the maximum pressure of the cycle or the initial expansion pressure of 200.0 pounds corresponding to an initial expansion temperature of 2195° Fahr., being attained shortly after the crank had passed over its inner dead-center, thus preventing the delivery of a dead-blow on the piston.

From the point *d*, the charge expands, driving the piston forward from A towards B at the expense of its own internal energy, the crank in the meantime revolving from 1 towards 3.

If the cylinder walls were non-conducting, the expansion would be adiabatic, but in actual practice a variety of conditions and circumstances causes the actual expansion line traced

by the indicator pencil to deviate not only from the path of an adiabatic line, but also from that of any calculated normal.

The probable conditions which cause these deviations may be briefly stated as follows:

1. During the passage of the crank from 4 to 5, the maximum pressure remains constant, and the movement of the piston from A to H causes the pencil to trace the actual line across the normal near the point *d*.

2. During the movement of the piston from H to G the variations in the speed of the piston occasion irregularities in the rate of expansion or increase of volume, which, in connection with the effect due to after-burning, cause the pencil to trace a line of varying pressures and temperatures crossing and recrossing the normal at different points such as *k* and *l*.

The theoretical consideration of these various causes and effects involves the analysis of a series of very complex problems of a more or less hypothetical character. Such analyses are unnecessary, however, as the indicator diagram affords the means by which the probable causes of actual effects may be determined with sufficient accuracy to serve the purposes of gas engine design and operation.

Data of this character may be most conveniently obtained by varying the position of the points of ignition and release in a manner somewhat similar to the shifting for the same purpose of the point of cut-off in the case of the steam engine.

In making the necessary tests, it is advisable to supplement the indicator diagrams with simultaneous observations of an *explosion-recorder*. This apparatus, mounted beside the indicator, gives a record of every stroke during two minutes; showing exactly the initial pressure of each explosion, the corresponding compression, how many and what explosions are

missed, defects in the controlling mechanism, etc., showing accurately the effect of any alteration.

Referring once more to the expansion curve of *Fig.* 24, it will be observed that the various causes of distortion, previously enumerated, have produced a considerable amount of "fattening" at the "toe" of the diagram, just where release occurs.

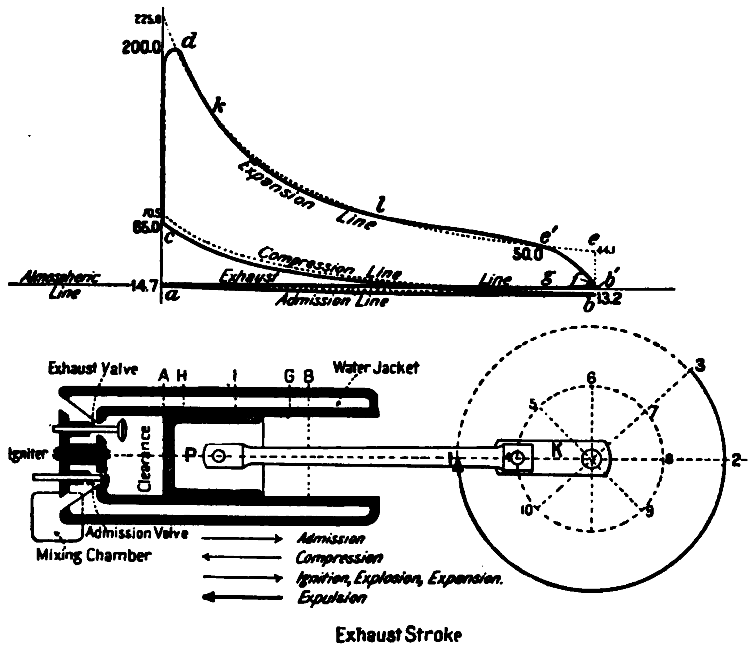


Fig. 25.—Indicator Diagram of Engine; Heating at Constant Volume (Paragraph 91)

In the present case, the point of release is taken at one-eighth of the piston stroke, and the diagram shows that the pressure at *é;* or the final expansion pressure, is about 50 pounds instead of 44.1 pounds which it would be if the exhaust valve were set to open at *e,* or the end of the piston stroke.

3. The opening of the exhaust valve causes a drop in pressure. If the valve opened instantaneously at the end of the piston stroke, the pressure would immediately drop to that of the atmosphere and the pencil would trace the line *eb′*; but in the present case the valve opens at the point *é* corresponding to the point G of the piston stroke, and while the pressure decreases the piston moves forward from G to B, and backward from B to G thus causing the pencil to trace the loop *éfg*.

91. Exhaust Stroke. Referring to *Fig.* 25, the backward movement of the piston from B to A expels the burnt gases from all parts of the cylinder except the clearance. During this operation, the indicator pencil will trace a line *ga* which will either coincide with, or lie above, the atmospheric line according to the following conditions.

1. If the exhaust valve is properly set and wire-drawing is not present, the pressure will be reduced to that of the atmosphere when the piston reaches the point G on its return stroke, and the exhaust line traced by the pencil will coincide with the atmospheric line.

2. If the exhaust valve is set so as to release at too high a pressure, and wire-drawing is present, the pencil will trace a line which will lie above the atmospheric line at a distance corresponding to the resulting back pressure.

92. Desirable Conditions for Engines Heating at Constant Volume. From the foregoing general reading of the indicator diagram of an engine heating at constant volume, it is clear that the desirable conditions for such an engine may be summarized as follows:

1. Since only one out of four strokes of the piston is a power stroke, heavy fly wheels must be used to equalize the motion of

the crank by storing up sufficient energy during the power stroke to overcome the resistance during the other three strokes.

2. Since a high initial expansion temperature and pressure with a low final expansion temperature and pressure are required to secure a high mean effective pressure, a rapid rate of inflammation or combustion is desirable, and requires the use of methods of ignition suitable for highly explosive mixtures.

93. **Indicator Diagram of Engine Heating at Constant Temperature.** As stated in paragraph 60, in the case of an engine heating at constant volume, the final compression pressure should always be sufficiently low to keep the final compression temperature below the ignition temperature of the charge; but in the case of an engine heating at constant temperature, the final compression pressure should always be high enough to raise the final compression temperature up to the ignition temperature of the charge.

The nearest actual approach to the cycle of an engine heating at constant temperature is that of the Diesel engine (pars. 65 and 239).

Fig. 26. shows the normal diagram of a Diesel engine in which the temperature of the charge is raised to about 986° Fahr., under a compression of 500 pounds. It will be noted, that in this case the final compression temperature of 986° Fahr., not only represents the ignition temperature of the fuel used, but also the constant initial expansion temperature of the cycle.

On the other hand, since the heating is actually due to slow combustion rather than explosion, it is quite doubtful whether the temperature is really constant during the process.

94. Indicator Diagram of Engine Heating at Constant Pressure. Referring to paragraphs 108 and 109, it will be noted that engines heating at constant pressure may operate by burning a charge introduced into the working cylinder under a compression pressure which will maintain the rate of inflow through the admission nozzle slightly greater than the rate of inflammation of the mixture; or by burning a charge, introduced into the working cylinder through a grating of wire gauze under a compression pressure which will supply a suffi-

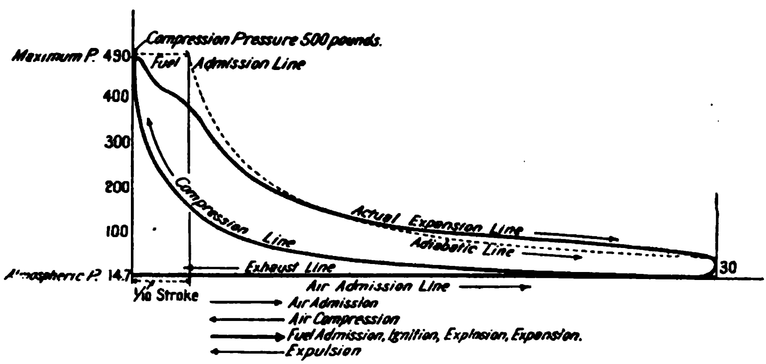


Fig. 26.—Indicator Diagram of Engine; Heating at Constant Temperature. (Paragraph 93)

cient quantity of the charge to evolve enough heat, by slow but continued combustion, to maintain a given constant pressure in the cylinder during a part of the stroke of the piston.

The nearest actual approach to the cycle of an engine heating at constant pressure is that of the Brayton engine (pars. 8 and 59).

Referring to *Fig.* 27: the charge is admitted at a compression pressure of 74 pounds and ignited the moment it passes through the grating. The heat evolved by the resulting combus-

tion raises the pressure until it is equivalent to the constant initial expansion pressure required, and is maintained at that pressure by the continued admission of the charge during one-quarter of the piston stroke. The supply of mixture is then cut-off, and the expansion allowed to continue until the pressure is reduced to very nearly that of the atmosphere at the end of the stroke.

Although the cycle is that of a single acting engine, having one power stroke for every revolution of the crank, or two

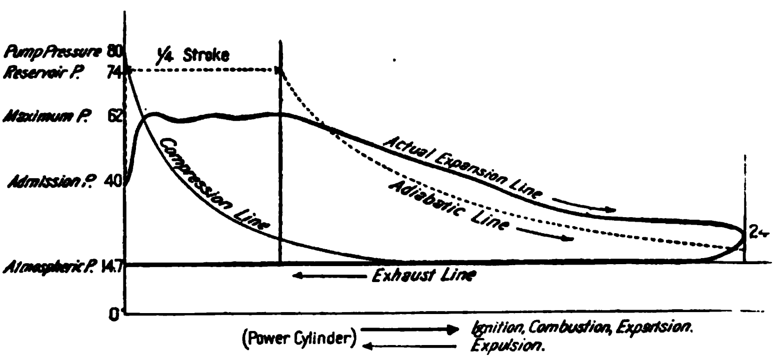


Fig. 27.—Indicator Diagram of Engine; Heating at Constant Pressure. (Paragraph 94)

strokes of the piston, it corresponds more nearly to that of a four-cycle engine than to that of a two-cycle engine. It will be understood, of course, that the compression line represents the pressure conditions in the compressing or auxiliary cylinder, which is one-half the size of the working cylinder.

The fact, that compressing the charge in an auxiliary cylinder eliminates practically all the difficulties attending the act of compression in the working cylinder, and also permits the reduction of the final expansion pressure to very nearly that of

the atmosphere without regard to the compression ratio, indicates that cycles heating at constant pressure ought to give more efficient engines than cycles heating at constant volume. The Brayton engine, however, never attained the success of any of the various types of engine heating at constant volume constructed previous to or since its time. The principal fault appears to have been due to poorly or improperly designed valves which caused an uneconomical consumption of fuel.

95. **Reading of Indicator Diagrams.** Referring to paragraph 78, it will be noted, that the form of an indicator diagram as given by the proportion of its height to its length may be varied at pleasure by the adoption of different linear scales to represent the units of pressure and volume. In actual practice, the linear scale of pressures varies according to the tension of the indicator spring, and that of volumes varies according to the diameter and stroke of the paper-carrying drum. Owing to the higher pressures, and the suddenness with which they are developed, the springs used in gas engine indicators are usually much stiffer than those used in steam engine work, the scale of the spring being in some cases as high as 400 pounds to the inch. Therefore, the actual indicator diagrams of gas engines appear to be much shorter vertically in proportion to their length horizontally, than those of steam engines, and when the actual figures for volumes and pressures are not given on the diagram it may lead to erroneous interpretations in making comparisons.

On this account it is well to understand clearly that the form of an indicator diagram, so far as it depends on the proportion of its vertical height to its horizontal length, has no significance for any purpose whatsoever.

On the other hand, the form of the diagram as given by the bounding lines is of the utmost significance, and variations of it not only permit the comparison of the cycles of different types of engine, but they also afford the only practical means by which the performances of a particular engine at different periods of its operation may be compared with each other.

Furthermore, if the actual performance of the engine falls below what is expected of it, or its normal working, the indicator diagram will show the nature, magnitude, and location of the adverse conditions and thus enable their rectification or elimination.

It is therefore quite evident that the value of an indicator diagram is not limited to its use for ascertaining the mean effective pressure for calculations of horse-power. (Par. 270).

That, although one of the most important, is nevertheless but one of the many uses of the diagram, and it requires only a knowledge of comparatively simple mathematics for the solution of the problem involved; while on the other hand the ability to read indicator diagrams accurately for the general purposes stated above, can only be acquired by long experience and practice.

Some instructive examples of particular cases will be found in Chapter X, based upon the action of different fuel gases under compression and during combustion. A careful study of Chapters VIII and IX will also prove materially useful in this connection.

CHAPTER VIII.

FUELS AND EXPLOSIVE MIXTURES.

96. Working Substances and Methods of Heating. As stated in Chapter III, the working substance of a heat engine may be a solid, a liquid, or a gas, which acts under the influence of heat derived from the combustion of a fuel, and which may be applied in various ways,—externally as in the case of a steam engine; both externally and internally as with the various types of hot-air engine; and internally in the gas engine.

Usually, the working substance is a gas, and the method of heating employed determines the character of the fuel that may be used to heat it in any particular class of engines.

For example: In the external-combustion method, the flame due to combustion does not come in direct contact with the working substance, therefore, highly inflammable fluids such as naphtha, alcohol, ether, etc., which change their form readily at low temperatures, may be satisfactorily used within certain limits of convenience and economy for the working substances of external combustion engines. On the other hand, in the internal-combustion method, the flame is brought into direct contact with the working substance, therefore, it is absolutely necessary that the working substance should be of a non-inflammable character.

Furthermore, in addition to the property of non-inflammability, it should possess in a marked degree the various qualifications which are desirable in all working substances, namely, accessibility, cheapness, safety, freedom from odor, and the capability of great expansion under a given temperature range (par. 31).

Since all of these qualifications are possessed by atmospheric air, it is quite natural that it should be exclusively selected for the working substance of all types of gas engine.

Having thus distinguished the working substance from the fuel of a gas engine, we are in position to consider the various forms of fuel by the combustion of which the enormous temperatures and pressures occurring in gas engine practice are attained.

97. **Sources of Heat Energy.** Any consideration relative to the character or quality of a fuel and its suitability for use in a power generator, necessarily involves the investigation of the natural sources of heat energy from which the fuel derives its own heating power.

It is quite clear, that all natural substances which may be made to liberate their inherent heat by oxidation or combustion, are sources of heat energy; but it may not follow, that all of them can be used successfully, or even satisfactorily, for fuel in connection with a power plant.

As in the case of a working substance, a fuel to be suitable for power-producing purposes should be accessible, cheap, and plentiful. It should be capable of being burned with convenient rapidity, and ought to contain a large amount of heat in small bulk.

Such fuels are usually compounds of carbon and hydrogen, which exist in nature, and are also manufactured, in the form of solids, liquids, and gases. The natural products are coal and wood, mineral, vegetable, and animal oils and fats; and natural gas. The manufactured products are coke and charcoal, petroleum distillates, alcohol, and artificial gas, which is of two kinds, illuminating gas and fuel gas, the latter be-

ing commonly known as producer gas, which is more fully described in Chapter IX.

98. **Sources of Gaseous Fuels for Gas Engines.** As stated in paragraph 96, the method of heating practically determines the character of the working substance. Likewise, the method of heating primarily determines the nature and form of the fuel most suitable for heating the working substances of the various classes of heat engines.

In the external-combustion method, fuels in any form, solid, liquid, or gaseous, may be conveniently and successfully used, with the advantage lying, however, decidedly in the direction of gaseous firing as against that of direct firing (par. 112); but in the internal-combustion method, the use of gaseous fuels is imperative, and tends to limit the available varieties of suitable fuel to certain kinds of hydrocarbon or carbon gases which are derived from the following sources:

1. Natural gas accumulations in Pennsylvania, Ohio and Indiana, also in different parts of the world, which afford hydrocarbon gases that vary in constitution and calorific value in the different localities.

2. Producer gas systems, affording two kinds of gas—a fuel gas rich in carbon but poor in hydrogen, and an illuminating gas which may also be used for power producing purposes.

3. Blast furnaces used in the smelting of iron from its ores, giving an out-flow gas of the producer variety, but much lower in calorific value, and containing very little if any hydrogen.

4. Carburetted air, which consists of various kinds of air-gas made by saturating atmospheric air with the volatile constituents of the liquid hydrocarbon.

It should be understood in this connection, however, that there is no fuel natural or artificial, not already in a gaseous

state, which may not be transformed into a gas by means of some one of the many gasifying processes known to science, and thus be made available for use in a gas engine. Also, that when oil is the source of heat energy, it is usually first converted into a gas by being injected into a chamber, filled with heated air, wherein it becomes vaporized in a manner similar to that of distillation by heat.

And furthermore, the value of any gaseous fuel for the production of power by means of gas engines depends not only upon its inherent heat energy or calorific value, but also upon its rate of combustion under certain conditions of temperature and pressure and the percentage burned in the cylinder.

99. **Calorific Values of Fuels.** The calorific value of a fuel is the amount of heat, expressed in thermal units, evolved by the complete combustion of a unit weight of the fuel in oxygen.

These values are determined by the use of an apparatus, known as a *calorimeter,* examples of which are illustrated in *Figs.* 139, 140, and described in par. 285. A *gas calorimeter* consists essentially of a small boiler, carefully lagged externally to prevent loss of heat to the atmosphere, to which the whole heat of combustion of a gas flame, as nearly as is possible, is transferred. Delicate and precise instruments record the weight of water heated, the increase in temperature which it has received, and the quantity of gas consumed in the operation. The heat units imparted to the water being observed, it becomes easy to calculate the calorific value of a cubic foot of gas.

The following table gives the calorific values of the principal fuels suitable for use in gas engines, expressed in British thermal units per unit of weight and volume.

100. Table of Calorific Values of Fuels.

FUEL.	B. T. U. Per Pound.	B. T. U. Per Cubic Foot.
Hydrogen, (burned to H_2O, water) at 32° Fahr.	62,032	349
Hydrogen, (burned to H_2O, steam) at 212° Fahr.	51,717	...
Carbon, (wood charcoal), burned to CO_2	14,544	...
Carbon, (burned to CO)	4,451	...
Carbon monoxide (burned to CO_2)	4,325	330
Anthracite Coal Gas	2,248	137
Bituminous Coal Gas	3,484	...
Marsh Gas CH_4 (burned to CO_2 and H_2O)	23,594	1,051
Olefiant Gas C_2H_4 (burned to CO_2 and H_2O)	21,430	627
Illuminating Gas, (28-candle-power)	......	950
Illuminating Gas, (19-candle-power)	......	800
Illuminating Gas, (15-candle-power)	......	620
Water Gas (American)	......	710
Semi-water Gas (American) Dowson	......	185
Coal Gas (English)	......	670
Natural Gas	......	500 — 1.050
Producer Gas (English)	......	150
Producer Gas (American)	......	137
Petroleum, (heavy crude oil) Penna.	20,737	...
Petroleum, (light crude oil) W. Va.	18,404	...
Petroleum, (heavy crude oil) W. Va.	18,332	...
Benzine	18,448	...
Gasoline	18,000 — 21,900	...
Gasoline Vapor	18,000 — 21,900	690
Acetylene C_2H_2	21,492	868
Natural Gas, Leechburg, Penna.	......	584
Natural Gas, Pittsburg, Penna.	......	500

101. British Thermal Unit—B. T. U. A British Thermal Unit is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit, at or about 39.1° Fahr., and represents a mechanical energy of 778 foot-pounds. (Par. 26.)

102. Calorific Value of a Compound Gas. The calorific value of a compound gas or a gaseous mixture such as the charge used in a gas engine, is the sum of the calorific values of its components, provided that in the chemical reaction due to combustion no heat is absorbed from outside sources. When heat is liberated by the chemical change the reaction is called *exothermic,* and when heat is absorbed, it is called *endothermic,* the character of the reaction depending upon the nature and percentage of the elements in the compound.

In the combustion of fuels in gas engines the chemical reaction is exothermic, the proportions of the components being either those of a known chemical combination for a true chemical compound, or the percentage of such as ascertained by a fuel analysis. In the latter case, the determination of the calorific value requires the use of mathematical formulae such as Dulong's or Mahler's, the former being accepted as correct within limits of error of five per cent., the deviations from the true values varying with the composition of the fuel.

103. Dulong's formula, when the sulphur present by analysis is considered, takes the forms:

Calorific Value in B. T. U.=

$$\tfrac{1}{100}\left[14{,}600\ C + 62{,}000\left(H - \tfrac{O}{8}\right) + 4050\ S\right]$$

Calorific Value in Calories =

$$\tfrac{1}{100}\left[8{,}140\ C + 34{,}400\left(H - \tfrac{O}{8}\right) + 2250\ S\right]$$

104. Mahler's formula in parallel form is as follows:

Calorific Value in Calories =

$$\tfrac{1}{100}\left[8{,}140\ C + 34{,}500\ H - 3000\ (O + N)\right]$$

in all of which, C = Carbon, H = Hydrogen, O = Oxygen, N = Nitrogen, and S = Sulphur. In every case the percentage of each constituent is to be taken, the final result being divided by 100.

105. **Combustion.** Since the attainment of a high temperature-range (par. 30) is the primary requisite in the action of a heat engine, it may be natural to infer that the value of a fuel will depend entirely upon its calorific value. It has already been stated in paragraph 97, however, that there are other conditions which are of equal if not greater importance.

It will be noted that the calorific value represents the amount of heat involved by the complete combustion of a fuel; but perfect combustion is a result seldom, if ever, attained in actual practice, and therefore, the actual temperatures of combustion must be lower than those which might naturally be expected from a fuel on the basis of its calorific value.

Observation and experiment have not only demonstrated the correctness of this supposition, but they have also established the fact, that, under certain conditions, higher temperatures of combustion may be reached by the use of fuels of low calorific value than those attained by the combustion of fuels of high calorific value.

In all fuels used in the gas engine, the principal heat-possessing elements are carbon and hydrogen. These exist in a great many chemical combinations of varying physical characteristics, and require different quantities of oxygen for their complete combustion.

106. **Products of Combustion.** In all cases, the products of their complete combustion contain only carbonic acid and

water, together with the nitrogen and some oxygen of the air supplied for the purposes of combustion, all of which have no intrinsic heat value.

On the other hand, when the combustion is incomplete, the products of combustion usually contain in varying proportions the additional elements, carbon monoxide, various hydrocarbons and hydrogen, with some tar and smoke as the products of distillation, all of which have intrinsic heat values, and which will combine with an additional supply of oxygen, evolve heat, and form other products of combustion that do not possess any heat value.

The usual form of incomplete combustion is the burning of carbon to carbon monoxide, which, upon the addition of the necessary supply of oxygen for complete combustion, will burn to carbon dioxide or carbonic acid. It is clear, that if any of the carbon in the fuel escapes without being completely burned, the result is a loss of the available heat energy of the fuel as represented by its calorific value, which tends to demonstrate, that the successful use of a fuel in a power generator depends as much, if not more, upon the means adopted to effect the complete combustion of the fuel, as upon its calorific value.

107. **Combustion Temperatures.** In the external-combustion method, no matter whether the combustion be complete or incomplete, or how high the temperature of combustion attained, the maximum temperature of the cycle of the working substance depends upon the heat absorbing capacity of the working substance under the accompanying conditions of pressure; the actual amount of heat utilized, under any circumstances, being only a small fraction of that evolved by combustion. Therefore, the attainment of complete combustion,

while important in its relation to fuel economy, is of limited significance with regard to thermal efficiency.

On the other hand, in the internal-combustion method, all of the heat evolved by combustion may be applied to the working substance. Therefore, complete combustion not only signifies maximum fuel economy, but also maximum thermal efficiency, and under proper conditions it should signify a higher percentage of heat utilization.

It is for this reason that the gas engine stands so far ahead of any type of external-combustion engine, in the matter of thermal efficiency and fuel economy.

108. Rate of Combustion. As stated in the foregoing paragraph, the value of a fuel for use in a power generator depends not only upon its calorific value, but also upon the method of its combustion. It is true that the internal combustion method enables the attainment of a closer approximation to complete combustion than that which may be attained by any other method, and therefore the amount of heat evolved approaches more nearly to the amount represented by the calorific value; still this does not necessarily indicate the actual attainment of a higher thermal efficiency.

The chemical reaction due to complete combustion may take place gradually, as in slow combustion, or very rapidly, as in the case of an explosion; the temperature of combustion increasing with the rapidity of the combustion. So that, while the calorific value depends upon the contained heat of the fuel, and is not affected by the rate of combustion, the temperature of combustion depends upon the rate of burning. This fact partially explains the cause of the high temperatures attained in gas engines by the use of fuels of low calorific value, and demon-

strates the advantage of the use of explosive mixtures; but it does not explain the cause of the varying combustion temperatures which may be attained by the complete combustion of the same or of different mixtures.

An explanation of the causes which produce the last named conditions requires an investigation of the laws which govern the rate of combustion of a mixture composed of an inflammable gas and oxygen in the proper proportions for complete combustion by a single explosion in mass. These laws as determined experimentally are as follows:

1. In any mixture, the rate of combustion is constant for a given temperature before ignition.

2. The rate of combustion increases with the increase of the temperature of the mixture before ignition.

3. The rate of combustion varies with the nature of the fuel components of the mixture; for example—it is very fast for mixtures of hydrogen, and slow for mixtures of marsh gas.

It is evident, that according to the first two laws, the rate of combustion of an explosive mixture may be made to vary by artificial means; for example, by *compression:* thus making the temperature of combustion partly dependent upon the cycle of the machine (pars. 40 and 45). This fact clearly demonstrates the value of compression in its relation to the thermal efficiency of an engine.

According to the third law, marsh gas with a calorific value per cubic foot, over three times that of hydrogen, has a slower rate of combustion than the latter; but the specific gravity of marsh gas (par 23) is also greater, being about nine times that of hydrogen; this indicates that the rate of combustion decreases with the increase of the specific gravity of the mixture,

such gases as air, oxygen, nitrogen, and carbonic acid being practically incombustible.

The significance of these conditions, in their relation to actual gas engine practice, will be more apparent when they are considered in connection with matters relative to the compression, ignition, and explosion of the gaseous mixtures used in gas engines, and the various methods of governing.

It will be noticed that the flame of ignition may be propagated through a gaseous mixture in three ways, each having its own peculiar effects upon the performance of the engine. First, when free to expand, each successive layer of mixture may flame and ignite the next, giving *uniform propagation;* second, the heat of combustion within a confined space may occasion a pressure wave, giving the flame *undulatory propagation;* and third, various causes may induce secondary waves synchronizing with and exaggerating the primary undulations, producing a momentary high pressure, called the wave of *explosive propagation.*

109. **Ratio of Combustion.** Referring to paragraph 23, it will be noted that while the calorific value of marsh gas, per cubic foot, is more than three times that of hydrogen, the calorific value of hydrogen per pound, is about 2½ times that, of marsh gas. Also, referring to the accompanying table, it will be noted, that although one pound of marsh gas requires for complete combustion only one-half the amount of air required for the complete combustion of a pound of hydrogen; yet, one cubic foot of marsh gas requires 9.5 cubic feet of atmospheric air for complete combustion, while one cubic foot of hydrogen requires only 2.4 cubic feet. It is also clear, that for a given cylinder capacity a larger percentage of hydrogen than of marsh gas can be burned at each charging.

Oxygen and Air Required for Combustion.

1 Pound of	Burning to (Products of Combustion)	Requires for Complete Combustion: Pounds of Oxygen	Pounds of Air	Cubic Feet of Air at 32° F.	Weight of Products of Combustion
Hydrogen, H......	H_2O, Water-vapor......	8.00	34.00	421	35.00
Carbon, C...	CO_2, Carbon dioxide....	2.66	11.30	140	12.30
Carbon, C.........	CO, Carbon monoxide...	1.33	5.65	70	6.60
Marsh Gas, CH_4...	CO_2 and H_2O..........	4.00	17.00	210	18.00
Olefiant Gas, C_2H_4	CO_2 and H_2O..........	3.45	14.58	180	15.60
Sulphur, S........	SO_2, Sulphur dioxide. .	1.00	4.25	53	5.25

Therefore, when computations are made to determine the increase in temperature due to the combustion of an analysed fuel, it will be found useful to determine the ratio between the mass of the fuel and the mass of its products of combustion. If y=mass of fuel, and x=mass of air required for complete combustion, then,—

$$\frac{y}{x+y} = \text{Ratio of Combustion} = R_c\,;$$

and for Hydrogen $R_c = \frac{1}{35} = .0285$; for Carbon, .0813; for Marsh gas, .0555; and for Olefiant gas, .0416.

110. Computation of Theoretical Combustion Temperatures. Referring to the foregoing paragraphs it will be noted, that, in the chemical reaction due to combustion or the chemical combination of one or more natural elements with oxygen, the heat evolved by the process raises the temperature of the products of combustion.

From paragraphs 18 to 23 it may be seen that the amount of heat required to raise the temperature of a substance through a given interval of the thermometric scale, depends upon the specific heat of the substance.

Therefore, if it be required to raise one pound of air from a temperature T_1 to a temperature T_2, and C represents its specific heat, the number of thermal units (H), necessary for this purpose will be $(T_2 - T_1)$ multiplied by C.

If the calorific value of one pound of fuel be represented by K, and its mass in pounds by y, and the mass of air required for its complete combustion by x (par. 109), then $x+y$ will represent the mass of the gaseous mixture, and $(x+y)$ C will be the amount of heat required to raise its temperature one degree; but the total number of thermal units corresponding to H will be yK, and for a mixture of $x + y$ pounds

$$yK = (x + y)\,C\,(T_2 - T_1);$$

or

$$\frac{y}{x+y} \times \frac{K}{C} = T_2 - T_1.$$

According to paragraph 109, $\frac{y}{x+y} = R_c$,

hence

$$R_c\left(\frac{K}{C}\right) = T_2 - T_1 =$$

= the theoretical temperature of combustion.

Referring to paragraph 23, it will be noted that gases have two specific heats—C_p the specific heat at constant pressure, and C_v the specific heat at constant volume, and the substitution of their respective values for C will depend upon the conditions of pressure or volume under which the combustion occurs.

Substituting in the above formula the values of K, R_c C_p and C_v, for hydrogen, carbon, marsh gas, and olefiant gas as determined by the physicist, and given in the tables in paragraph 23, the theoretical combustion temperatures of mixtures

composed of these elements and air may be computed as follows:

Assuming that the specific heat of the mixture is known and that it does not change during the process of combustion, the values of K, R_o, etc., for a mixture of hydrogen and air are as follows: K = 62,032; R_o = .0285; C_p = 0.237; and C_v = 0.169, and if the average specific heat of the mixture be assumed as being equal to that of air at constant pressure, then the theoretical combustion temperature of the mixture will be—

$$.0285 \times \frac{62{,}032}{0.237} = 7358^\circ$$

when the combustion occurs at constant pressure, and

$$.0285 \times \frac{62{,}032}{0.169} = 10{,}461^\circ$$

when the combustion occurs at constant volume.

111. **Table of Theoretical Combustion Temperatures.** The accompanying table gives the computed theoretical combustion temperatures of the more important heating elements which constitute the fuel components of the gaseous mixtures used in gas engines; but it is a fact, however, that no such temperatures are attained in actual gas engine practice, and therefore, in calculating the power actually developed by the combustion and expansion of mixtures of gas and air, it becomes necessary to ascertain the actual value of the specific heats of such mixtures during the process of their combustion in the cylinders of gas engines, and to determine whether these values remain constant for all temperatures.

Table of Theoretical Combustion Temperatures.

	Burning at Constant Pressure.	Burning at Constant Volume.
Hydrogen, H..........	7,358°	10,461°
Carbon, C..............	4,802°	6,785°
Marsh Gas, CH_4........	5,525°	7,748°
Olefiant Gas, C_2H_4.....	8,761°	5.275°

This subject will be found more fully considered in Chap. X.

CHAPTER IX.

GAS PRODUCER SYSTEMS.

112. **Methods of Combustion.** The phenomena of combustion consist of the more or less rapid oxidation of the fuel, that is, the combination of its carbon, hydrogen or other combustible elements with the oxygen of the atmosphere, the process being accompanied by the evolution of heat and, generally, light. Thus, the process of respiration, which oxidizes impurities from the blood in the lungs, creating bodily warmth, varies in degree, and not in kind, from the fierce heat of a steel furnace. It is evident, therefore, that the primary requisite of combustion is the gasification of any fuel to be consumed, the nature and heat-value of such gaseous product depending upon the fuel from which, and the method by which, it is obtained.

In utilizing solid fuels by the ordinary methods of burning on a grate, constituting *direct firing,* the various constituents are distilled, gasified or vaporized, and the gaseous products burnt in contact with, or in close proximity to, the fuel-bed. The earlier processes of gasification, however, absorb more or less heat, from the high temperatures developed by the later combustion of the gases, hence it is advantageous, when seeking the highest efficiency of combustion, to separate the former from the latter stages.

This separation is accomplished by the aid of the *gas producer.* In it the fuel is volatilized by means of a retarded combustion, producing a combustible gas, which may be stored against requirements, or led away through conduits to a separate combustion chamber, where it may be burnt under condi-

tions permitting a fuller utilization of the natural heat of the fuel than can be obtained by any method of direct firing.

It must not be thought, however, that the gas producer generates more heat than is possible with grate firing; on the contrary, its use is accompanied, even under most favorable conditions, by a theoretical loss of one-fifth of the total heat-energy of the fuel. What is effected, is the better application of the heat generated, so that the actual consumption is less than by the older method, notwithstanding the loss mentioned. This is especially noticeable with gas engines worked by producer gas, small plants having an economy of consumption scarcely equalled by the largest and most elaborate steam installations.

113. **Generation of Producer Gas.** As already stated, producer gas is the product of an incomplete or retarded combustion of the fuel. This is effected by burning the latter in a bed, *several feet in thickness,* within the *generator* or producer proper. The heated gases and flame from the portion nearest the air supply, where combustion is more or less rapid and complete, have to pass through the remainder of the bed, distilling gases from the latter in their transit. Referring to paragraphs 105 and 106, the processes of combustion within the generator may be described as follows:

The oxygen, (O), of the atmosphere combines with the fuel in the first portion of the bed, and the ensuing combustion results in the formation of carbon dioxide (CO_2), that is to say, each atom of carbon combines with two atoms of oxygen. This means that each pound of carbon requires $2\frac{2}{3}$ pounds of oxygen, the combination resulting in the formation of $3\frac{2}{3}$ pounds carbon dioxide, and, at the same time, imparting about 14,500 heat units to the mass of fuel.

The first reaction may be expressed by the equation

$$\underset{\text{Carbon}}{C} + \underset{\text{Oxygen}}{2O} = \underset{\text{Carbon dioxide}}{CO_2}$$

The second reaction takes place within the fuel bed, and is occasioned by the carbon dioxide molecule absorbing another carbon atom from the glowing fuel, becoming reduced to carbon monoxide. This is shown by the equation

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Carbon}}{C} + \text{heat} = \underset{\text{Carbon monoxide}}{2CO}$$

The effect of this process is that the $3\frac{2}{3}$ pounds of carbon dioxide assimilate another pound of carbon, forming $4\frac{2}{3}$ pounds of carbon monoxide, which is equivalent to the evolution of $2\frac{1}{3}$ pounds of the latter gas for each pound of carbon consumed.

114. **Processes within the Producer.** The first two reactions in the generator constitute what is termed incomplete combustion, consisting of the formation of carbon dioxide and the decomposition of the compound into the monoxide. The result of the process is the same as if the pound of carbon had been burnt directly to carbon monoxide, thus developing 4,451 B. T. U. for each pound of C burnt to CO. This heat is apparent as the sensible heat of the fuel bed and generator.

The carbon monoxide may be caused to combine with fresh oxygen at any time after it has left the producer, this second combustion to CO_2 being accompanied by the evolution of $14{,}544 - 4{,}451 = 10{,}093$ B. T. U., the heat value of CO to CO_2 per pound of carbon contained.

Now, atmospheric air is a mechanical mixture of oxygen, which supports combustion, and of nitrogen, which is an inert gas serving as a diluent. The proportions, by weight, are:

oxygen, 23 per cent.; nitrogen, 77 per cent. Therefore, accompanying and diluting the $2\frac{1}{3}$ pounds of carbon monoxide, resulting from the reaction in the producer, there will be about 4.46 pounds of nitrogen, the whole forming about 6.8 pounds of lean gas.

115. **Use of Steam in Connection with Gas Producers.** The object of the gas producer being the generation of a combustible gas of high heat-value, it is desirable to use as little as possible of the inherent heat energy of the fuel during its gasification. The only sensible heat necessary is that which raises the fuel to incandescence so as to reduce the carbon dioxide to monoxide. Now, there are some 4,451 heat units generated in burning a pound of carbon to carbon monoxide, and as only part of this heat passes away with the gases or is dissipated by radiation from the generator, it may be said that there is a surplus of about 2,500 B. T. U. per pound of carbon over and above what is necessary for the working of the furnace. This extra heat requires to be utilized in order to get the greatest efficiency from the generator and to keep the temperature down, a temperature of 1900° Fahr. having been found to give a minimum of CO_2 or a maximum of CO.

This surplus of heat is utilized in the most effective manner by the introduction of steam into the generator. Steam may be decomposed into its constituent elements, oxygen and hydrogen (H), when in contact with glowing carbon at a sufficient temperature, the process being expressed thus

$$\underset{\substack{\text{Water}\\\text{vapor}}}{H_2O} + \underset{\text{Carbon}}{C} + \text{heat} = \underset{\text{Hydrogen}}{2H} + \underset{\substack{\text{Carbon}\\\text{monoxide}}}{CO}$$

Each pound of steam on being decomposed, liberates $\frac{1}{9}$ pound hydrogen and $\frac{8}{9}$ pound oxygen, the latter combining with $\frac{2}{3}$ pound carbon to form $1\frac{5}{9}$ pounds of carbon monoxide,

this extra amount being produced without the introduction of any more inert nitrogen into the apparatus.

In order to effect the decomposition of one pound of steam, in the presence of incandescent carbon, 6,800 heat units are necessary, and as there are only about 2,500 B. T. U. available for the purpose from the burning of each pound of carbon, the quantity of steam that can be taken care of is $\frac{2500}{6800}$ or about 0.37 pound. This yields about 0.325 pounds oxygen which combines with about 0.245 pounds carbon, yielding 0.57 pounds of the monoxide, which is equivalent to saying that about one-fifth of the total carbon can be gasified by the aid of the steam. The hydrogen liberated will be about 0.033 pounds for each pound of total carbon gasified in all reactions.

116. **Total Heat Value of Producer Gas.** Any volatile hydrocarbons present in the fuel will become mixed with the other distillates, as will also marsh gas (CH_4), olefiant gas (C_2H_4), adding to the total heat, which will range from about 135 B. T. U. per cubic foot of gas generated, when derived from anthracite, up to 150 or 160 B. T. U. per cubic foot of bituminous producer gas. Some carbon dioxide, say from four to six per cent., will generally be present, it being practically impossible to reduce all this gas except under high temperatures and slow gasification. Owing to the conflict of these conditions with the lowering of the temperature occasioned by the admission of steam, an excess of the latter is inadvisable. This would largely increase the proportion of valueless carbon dioxide, a loss not counterbalanced by the gain in hydrogen.

The heat proportions of anthracite producer gas may be stated as follows, the heat units being taken at atmospheric pressure and a temperature of 60° Fahr.

		Per cent. Volume.	Heat units. Cubic foot.
Carbon dioxide	CO_2	2.5	0
Carbon monoxide	CO	28	96
Hydrogen	H	9	31
Marsh gas	CH_4	1	10
Nitrogen	N	59.5	0
		100 vol.	137 B. T.U.

117. **Heat per Pound of Fuel.** The amount of heat obtained from each pound of fuel gasified may be taken as:

	B. T. U.
Heat from carbon monoxide	10,093
Heat in hydrogen reclaimed by heat of gasification.	2,047
Heat from hydrocarbons in fuel, assuming 1 per cent.	215
Total heat value	12,355

118. **Conditions Affecting the Use of a Producer.** When the gas is generated for fuel, as under boilers or in steel furnaces, the products of distillation may be led directly from the generator to the furnace. In such cases any convenient fuel may be disposed of, such as sawdust, tanbark, culm, lignite, etc., the system lending itself to the utilization of otherwise waste materials.

For ordinary producers, working in connection with gas engines, it is necessary to wash and filter the gases before they are used, in order to remove tarry or carbonaceous particles which would be detrimental to the working of the engine. For the same reasons, many engineers prefer to use anthracite coal

or coke to the exclusion of bituminous or soft coals. These, however, as well as the refuse matters indicated above, may be safely used in a down-draught generator.

119. **Taylor Gas Producer.** *Fig.* 28 shows a section of a Taylor Producer, which may be taken as typical of a generator using anthracite coal.

The incandescent fuel is supported upon a bed of ash, this resting on a revolving table, A, which is larger in diameter than the bosh, B, the ashes forming a natural slope of about 55°. As they are formed, the ashes fall into the sealed ashpit, C.

In regular operation, the line between the ashes and fuel is kept about six inches above the cap, D, of the central air pipe, E, so that the fire comes into contact with the brick lining only, all iron work being kept away from the heat. This height is maintained constant by grinding or revolving the ash table once every 6 to 24 hours according to the rate of working.

The blast is usually furnished by a steam jet blower, but a fan blower may be used if more convenient, a small steam pipe being run into the vertical air pipe to supply the steam required for softening the clinkers and maintaining the proper temperature of the producer. This producer is equipped with the Bildt continuous *automatic feed device,* F, which consists of a *receiving hopper,* G, surmounting the main *storage magazine,* H, the communication between the two being regulated by a horizontal *rotary register,* J, operated by a lever. The *distributor plate* K, is suspended below the main magazine, and is supported by a steel shaft, L, which passes upward through the storage cylinder. Both the hood of the distributor plate and the inverted conical base of the magazine are water-cooled, thus facili-

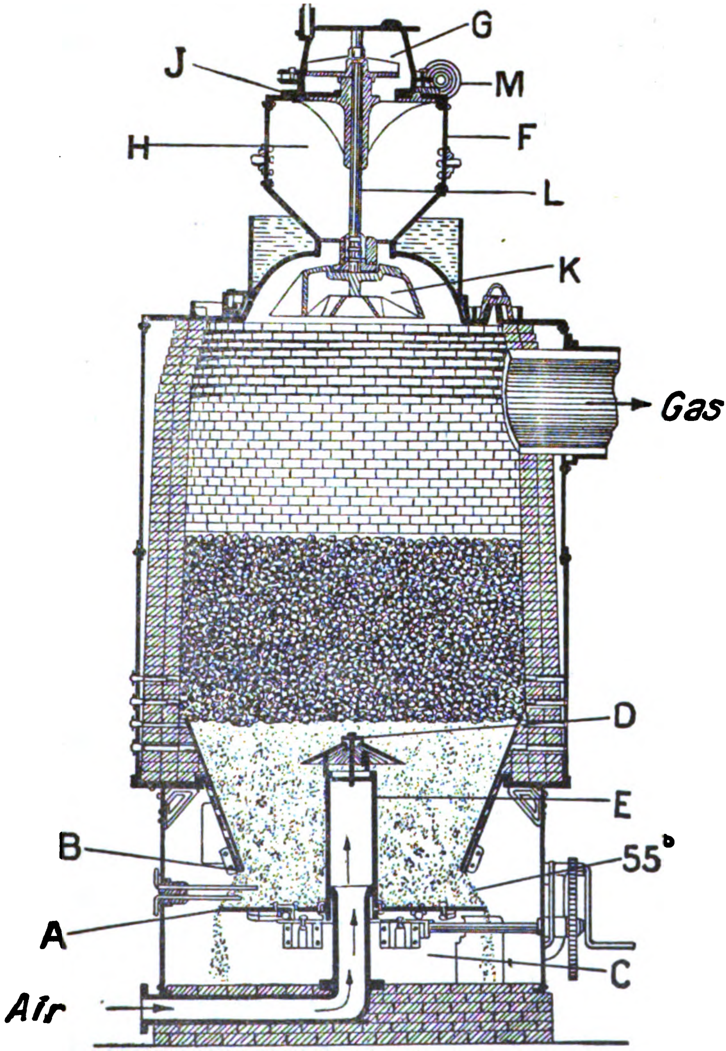


Fig. 28.—Taylor Gas Producer.
(Paragraph 119)

tating the discharge of strongly caking coals. The receiving hopper is rotated by means of a worm wheel and worm attached to the upper end of the shaft, and the distributor plate is revolved through the radial arms and hub of the receiving hopper, which are also keyed to the shaft. A *hand-wheel nut* on the threaded end of the axis affords the means for adjusting the distance between the distributor plate and the coal reservoir. This adjustment, together with the variable speed secured by means of the step cone pulley, M, permits of a ready control of the rate of coal discharge.

120. **Types of Gas Producer Systems.** The foregoing paragraph gives the description of a gas producer which embodies in its general construction and method of operation the principal features of the successful gas producers of the modern type. These producers may be used for the production of gas from different kinds of fuel, suitable for various purposes, but when employed in connection with gas engine work they form portions of two general but well-defined systems of gas production—the *Pressure System* and the *Suction System.*

In the pressure system, the air required for the generation of the gas is delivered to the gas producer under pressure derived from an auxiliary source, and the gas generated in the producer is delivered to the engine under the same pressure.

In the suction system, both the passage of the air through the producer and the introduction of the gas generated therein into the cylinder of the engine is effected by the sucking action of the piston during its forward or charging stroke.

Although the pressure producer is usually composed of more cumbrous apparatus, and requires more space for its instal-

lation, it possesses greater elasticity than the suction system for meeting variations in fuel conditions, and has greater capacity for utilizing different kinds and cheaper grades of fuel. It is undoubtedly the better for use in connection with large power units, and in cases where several gas engines are operated from the same producer plant.

On the other hand, for isolated plants of small capacity, or where only a single gas engine of medium power is used intermittently, the application of the suction system not only enables the simplification of matters relative to bulk and the reduction of cost, but it affords the more important advantage of making the demand of the engine for gas the controlling factor in the generation of the gas from the solid fuel.

121. **Pressure Gas Producer System.** As shown by *Fig.* 29, a pressure gas producer system usually consists of the following parts:—

A small steam *boiler,* A, for making steam and producing the necessary air pressure; a gas *producer,* B, equipped with a continuous feed arrangement; an *economizer,* C, with *superheater* and *wash box;* a *scrubber,* D, a *purifier* E; a *gas holder,* F, consisting of a steel tank supported by guide framing upon which it travels up and down; and suitable *drips* and connections.

The details of the several portions may be considerably modified to suit varying conditions; as, for instance,—the boiler may be omitted in cases where steam is procurable from any other convenient source, or, in some cases, the separate steam generator may be absolutely unnecessary.

For smaller equipments, or those suitable for operating engines ranging in power up to 500 horse, single producers are

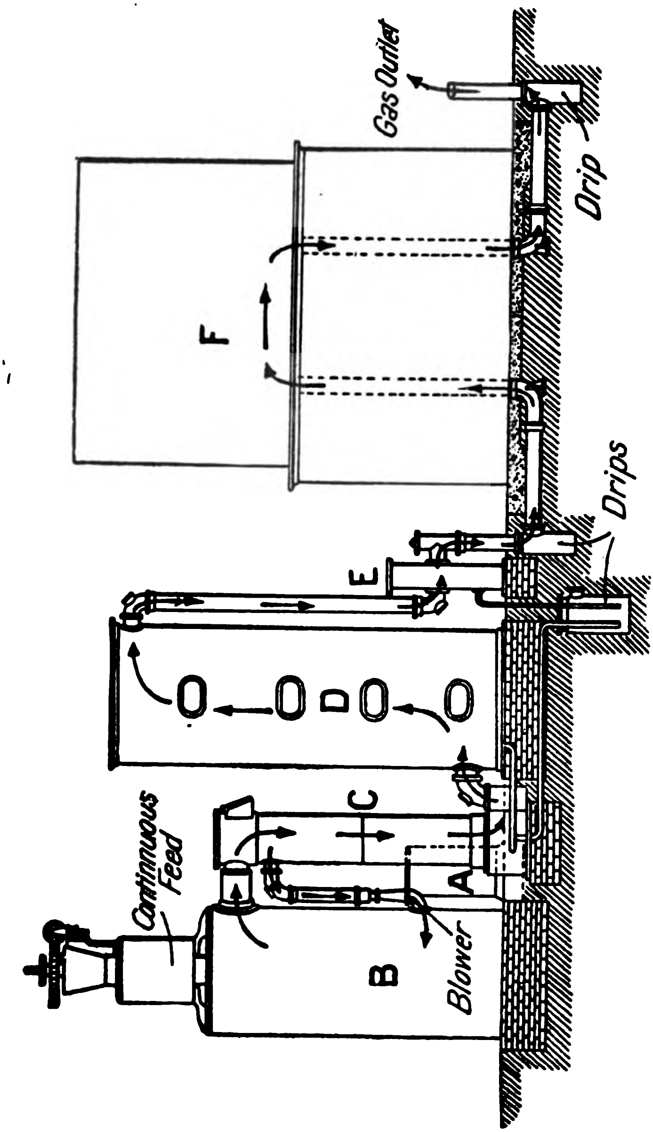


Fig. 29.—Pressure Gas Producer System.
(Paragraph 121)

considered sufficient, but larger equipments should be provided with two or more producers, the general design and arrangement of which may be varied to suit the local conditions.

In operation, the gases generated in the producer enter the superheater and economizer. In the economizer the air blast of the producer travels in a direction opposite to that of the blower, and the gas passing through the wash box deposits a large portion of its extraneous suspended matter. Here also is located the seal or non-return against the gases stored in the holder and present in the other parts of the system. From the wash box the gas enters the scrubber, in which it travels against sprays of water through compartments filled with coke and is still further purified by the removal of any tarry substances, sulphur, or ammonia which it might contain, prior to its introduction into the purifier where the purifying operation is completed. From the purifier the gas passes into the holder which stores up a supply sufficient for starting and for running several minutes, its chief purpose being the regulation of pressure and variations in the consumption and mixture of gases.

122. Suction Gas Producer System. As already stated in paragraph 120, the operation of a suction gas producer system depends upon the sucking action of the engine piston during its forward or charging strokes, which action tends to draw the air supply through the fuel bed of the producer, and the gas generated into the engine cylinder.

In *Fig.* 30, which shows the general arrangement of the various adjuncts of a suction system, A represents the *producer;* B the *evaporator;* C the *scrubber;* and D the *receiver.* The operation of the system may be described as follows: The

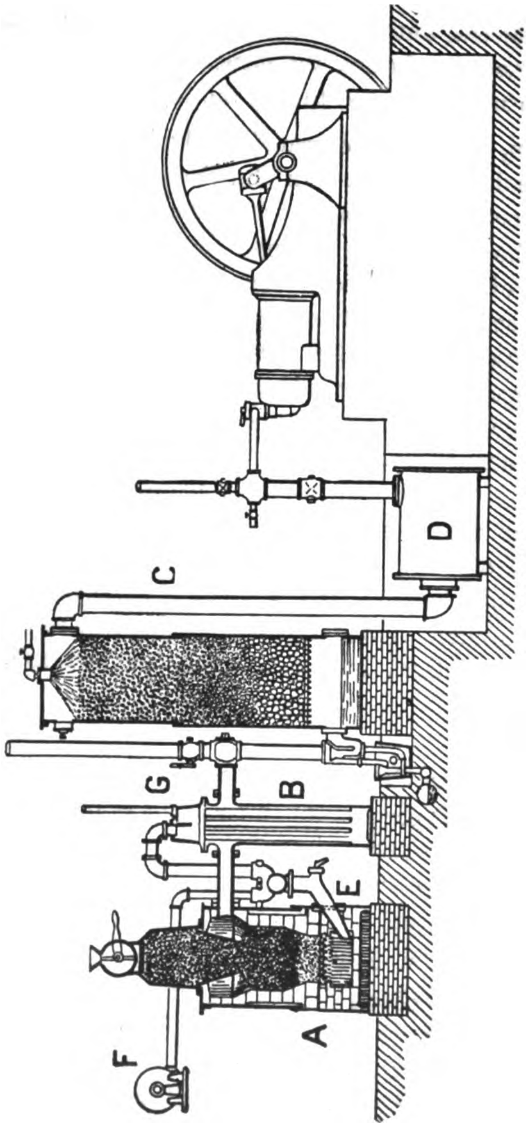


Fig. 20.—Suction Gas Producer System.
(Paragraph 122)

gases generated in the producer pass through the evaporator, which is practically a small multitubular boiler, and furnish the sensible heat required for evaporating the water. The resultant vapor is conducted to the ash pit of the producer through the pipe E, by the sucking effect in the producer, while the gas passes from the evaporator to the scrubber filled with coke. As the gas rises through the interstices of the coke, the washing water descends and not only takes up and removes the dust brought over by the gas, but also clears it of ammonia and other impurities which have a tendency to combine readily with water. From the scrubber the gas passes to the receiver or *suction box.*

The diameter of the receiver being relatively much larger than that of the suction pipe of the engine, the strokes of the engine piston do not therefore cause pulsations between the receiver and the producer.

The producer is usually provided with a charging hopper capable of holding enough fuel for several hours' operation, in the smaller sizes, and allows the admission of fuel to the combustion chamber without permitting access of air thereto during the charging operation.

In operating, a fire is kindled upon the grate, the fuel bed built thereon, and the air necessary for starting combustion supplied by means of a hand or belt-driven *fan*, F. The poor and lean gas produced at starting is first allowed to escape into the open air through the *vent pipe,* G, until the test cock shows that good gas is being produced. The pipe, G, is then closed and the scrubber and receiver are brought into the gas circuit. The engine is now put in operation and as it thereafter performs the function of the fan, the latter is stopped, the operation of the entire system becoming absolutely automatic.

123. Loomis-Pettibone Producer. This combines in itself the good points of both the pressure and suction systems, having the ability to meet a fluctuating demand from several small units which characterizes the former, together with the equable and easily controllable combustion of the latter. In addition, it has a distinct and valuable feature of its own, the *down draught generator*, which causes all distilled hydrocarbons or *tars* to pass downwards through a thick bed of incandescent fuel which volatilizes them into *fixed* gases. This at once eliminates the tarry matters which prevent the successful operation of gas engines, and whose presence in bituminous coals confine most producers to the use of anthracite or coke alone.

Referring to the illustration, *Fig.* 31, it will be observed that the generator or producer, proper, consists of a pair of cylindrical steel shells, lined with fire-brick. The object of building it in halves is to allow the cleaning of one fire without interfering with the generation of gas in the other chamber. To permit this, shut-off valves at A and B, are fitted to each chamber; they are water-cooled to prevent burning.

There are no fire-bars, the fuel bed resting upon a perforated fire-brick arch; ashes are removed through doors in the shell above this arch, and others in the ash pits, J and K.

The fuel is fed into each generator through the doors, H and I, these being continually open, while the apparatus is running, for the purpose of admitting air. Steam is blown into the upper part of each chamber at E and F, the dissociation of this steam liberating hydrogen gas and quickening the combustion of the other fuels. The resultant gas is drawn down through the bed of glowing fuel, during which passage all tars are volatilized to gases, and pass through the purifying apparatus to the holder.

The second steam pipe fitted to each generator is for the purpose of livening up the fire, instead of slicing or poking it; to use it, the outlet valve, A or B, is closed and the jet turned on into the ash-pit space; this clears the archway perforations.

The *evaporator* or tubular boiler is traversed by the hot gases on their way from the generators, thus effecting economy in raising the necessary steam, besides appreciably cooling the heated products of combustion. They are further cooled in passing through the pipe leading to the water space at the foot of the *scrubber*.

124. Action of Scrubber. The gas passes a diaphragm and bubbles up through this water traveling through various trays filled with broken coke, while it meets with sprays of water falling downward, which thoroughly wash or *scrub* the gases of their impurities, also effectually cooling them. Two trays of excelsior (wood-shavings) occupy the upper part of the scrubber, to assist the purification.

The water spray absorbs ammonia and other impurities from the ascending gases as it comes in contact with them by their passage through the coke. The liquor falling to the bottom of the scrubber is drained off by a suitable drip into a collecting sump, its surface being maintained at a constant level to cover the diaphragm on the gas inlet.

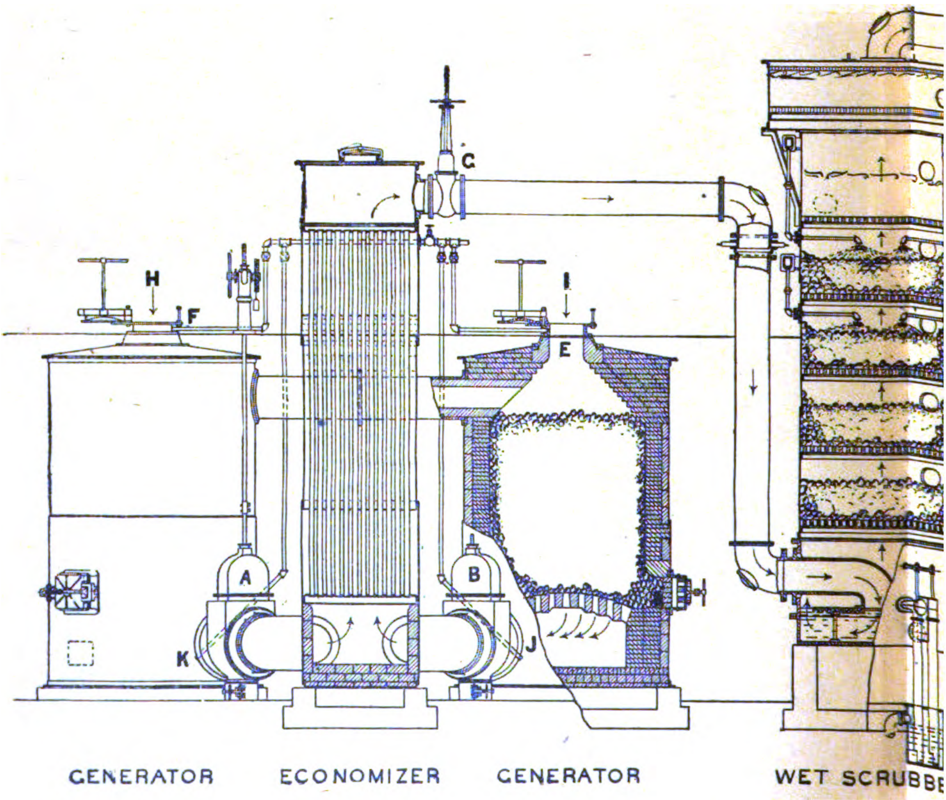
The *exhauster* comes next in the system; it is advantageously placed between the wet and dry scrubbers, thus effecting a suction draught, with its equable combustion, through the generator and scrubber while it forces the gas through the dry filter and into the holder, maintaining the pressure which raises the latter. The exhauster is driven either by a steam engine, electric motor or other suitable means, and

is ingeniously controlled by means of levers and stops on the gas holder, similar to the controlling apparatus on a hydraulic accumulator. By this means, the exhauster is checked or stopped when the holder reaches its upward limit, starting again as the holder descends. As the combustion in the generators is manifestly dependent upon the suction created by the fan, its slackening or stopping checks the output of gas, thus regulating its manufacture exactly according to the needs of the system fed from the holder.

A by-pass pipe with a weighted flap valve is seen to the left of the exhauster, this is to prevent damage to the fan should both outlet valves be accidently closed in changing from one filter to another or in closing the purge pipe. In such case the current from the exhauster flows back, lifts the safety valve and circulates through the fan until the outlet is open, when the flap safety valve closes.

The pipe and valve, marked, C, constitute the *stack valve* and *purge pipe;* this is used in starting. When lighting the fires, the change valve, C, is opened and the outlet, D, closed, the exhauster being set in motion. The gases are blown out through, C, until good gas appears, when, D, is opened and, C, closed, the process of generation continuing thereafter. A period of fifteen to twenty minutes is usually sufficient for starting the apparatus.

The outlet valve, D, leads to the *filters,* purifiers, or dry-scrubbers, consisting of two super-posed cylindrical chambers filled with excelsior; these are so arranged that either may be worked while the other is being cleaned. The filters take out any lampblack or dusty impurities which have not been removed by the water spray in the wet scrubber, and also absorb any remaining moisture.



G
H
F
I
E
A
B
K
J
GENERATOR
ECONOMIZER
GENERATOR
WET SCRUBBE

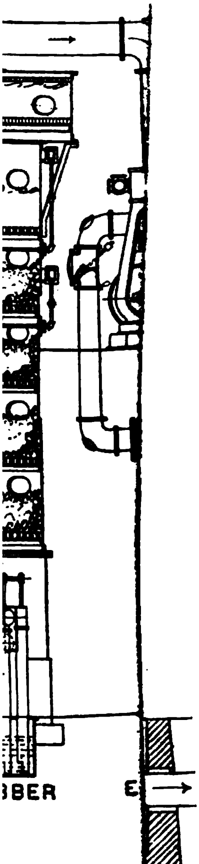


FIG.

From the dry filters the gas proceeds into the holder or *gasometer,* which is of the ordinary gas works pattern, usually with a single lift. The base of the gasholder is filled with a water seal, as is customary. The weight of the telescopic part or lift of the gasometer is what gives the pressure in the supply main, and is balanced by the blast from the exhauster, thus serving the same purpose as a hydraulic accumulator. The relative size of the holder depends upon whether the demand for power is steady or fluctuating. A fair average capacity for steady output is 3 to 4 cubic feet per indicated horse-power.

From the gas-holder, the cool dry gas passes to the various engines as required.

125. Average Volumetric Analyses of Gases.

		Natural Gas.	Coal Gas.	Water Gas.	Producer Gas, Bituminous.
Carbon dioxide	CO_2	0.26	0.5	4.0	2.5
Carbon monoxide	CO	0.50	6.0	45.0	27.0
Hydrogen	H	2.18	46.0	45.0	12.0
Marsh Gas	CH_4	92.60	40.0	2.0	2.5
Ethylene	C_2H_4	0.31	4.0	....	0.4
Nitrogen	N	3.61	1.5	2.0	55.3
Oxygen	O	0.34	0.5	0.5	0.3
Water vapor	H_2O	....	1.5	1.5	....
Weight of 1,000 cu. ft., lbs.		45.6	32.0	45 6	65.9
B. T. U. in one cubic foot.		1,100	735	322	157

126. Yield of Gas. The following fuels will yield in cubic feet per pound weight: Buckwheat anthracite, 85; bituminous coal, 75; brown coal or lignite, 55; peat, 45.

CHAPTER X.

COMPRESSION, IGNITION, AND COMBUSTION.

127. Effect of Compression on Actual Combustion Temperature. Referring to paragraph 108, it will be noted that the temperature of combustion of a fuel, which in the case of a gas engine signifies the maximum temperature of the cycle of the working substance, depends upon the rate of combustion of the explosive mixture or charge, and that this rate may be made to vary by the application of compression, thus making the maximum temperature dependent to a certain extent upon the amount of compression, and therefore more or less independent of the calorific value of the fuel component of the charge.

Specifically stated, the rate of combustion of a gaseous mixture increases with the increase of its temperature before ignition, or with the increase of its equivalent, the final compression temperature.

Referring to paragraph 89, it will be noted that the principal factors, which affect the final compression temperature under actual working conditions, are the dilution of the explosive mixture or charge, the quality and character of the products of the previous combustion remaining in the clearance space of the cylinder after exhaust, the specific heat of the explosive mixture, the compression ratio, the piston speed, and the temperature of the jacket-water.

128. Properties of Explosive Mixtures. It is well known that a mixture composed of an inflammable gas and oxygen in certain proportions is explosive, that is, its rate of combustion is so rapid as to be practically instantaneous.

This condition obtains when the gas and air are present in quantities exactly sufficient for the perfect chemical combination of the two elements, or the complete combustion of the fuel gas in oxygen, and the evolution of all its heat energy as represented by its calorific value.

129. Dilution. Therefore, it is evident that if the mixture be diluted either by increasing the proportion of oxygen, or by the introduction of inert gases such as the products of combustion which remain in the clearance space of a non-scavenging engine at the end of the exhaust stroke of the piston, the rapidity of combustion of the mixture will decrease, passing from that of explosion to one of slow burning as the amount of dilution is increased, and finally it will reach a condition of non-inflammability directly due to an excess or an insufficiency of oxygen.

This explains the reason why a mixture either too rich or too lean will not ignite under compression suitable for a charge containing gas and air in proper proportions.

It will be understood, of course, that the proportion of oxygen required in a true explosive mixture will vary according to the character of the fuel gas used, but, as a general rule, explosive mixtures of coal gas and air require at least 6 volumes of air to 1 of gas. Below this proportion, the quantity of oxygen is insufficient for the proper combustion of the fuel gas, and above it, the rate of combustion, and therefore the force of the explosion grows weaker and weaker as the proportion of air is increased. On the other hand, while the actual pressures developed are reduced as the proportion of air is increased, the efficiency of the mixture increases until it contains about 11 volumes of air to 1 of gas, when it begins to

decrease, until finally the attenuation is so great that the charge fails to ignite.

This is due to the fact, that although the increase of temperature per cubic foot of mixture is less, the increase per cubic inch of gas is greater, which demonstrates the economy of using dilute mixtures, provided the loss of inflammability of the charge can be restored by compression without imposing an undue load on the piston.

This is exactly the effect of compression in a properly designed gas engine, the effective power due to the increased ratio of expansion more than compensating the expended power due to the increased ratio of compression.

A better understanding of this process may be had by a brief survey of certain experimentally determined facts relative to the inflammability of gaseous mixtures.

130. **Inflammability of Gaseous Mixtures.** As ascertained by practical tests, if an explosive mixture of hydrogen and air be reduced in pressure to one-eighteenth of an atmosphere, it cannot be inflamed by the electric spark; but if it is heated at this pressure to a dull red, its inflammability will be restored and it will become susceptible to ignition by the spark.

Furthermore, one volume of such a mixture, with an addition of nine volumes of oxygen, is not inflammable; but if its pressure be increased, or its temperature raised, it will readily become so.

The excess, which reduces or destroys the inflammability of the mixture, increases or decreases with the temperature, so that heating a mixture not only widens the range of dilution either with excess or inert gas, but also the range of reduction of pressure.

It is clear, that, to a certain extent, under these conditions,

mixtures more and more dilute can be used as the piston speed increases. This increase of speed prevents the loss of heat of compression, through conduction from the charge to the cylinder walls, by reducing the time of compression, giving thereby an increase of economy independent of the amount of compression.

131. **Dissociation.** The tables given in the following paragraphs, 132, 133, and 134, afford data for the computation of the temperatures and pressures usually occurring in gas engine work.

It will be noted that, the combustion temperatures of explosive mixtures given in paragraph 133, are much lower than what might be expected from the magnitude of the theoretical combustion temperatures given in paragraph 111.

This is undoubtedly due to dissociation or chemical decomposition of the gases, comprising the mixture, by the agency of great heat, so that they absorb as much heat as would be evolved by the formation of the products of partial combustion.

132. **Usual Compression Temperatures and Pressures.** The accompanying table may be used for determining the compression temperatures and pressures which usually occur in gas engine work as follows:

To determine the compression temperature corresponding to any initial temperature, when the initial temperature and the compression ratio are given, multiply the given initial temperature by $\frac{1}{100}$ of the number in the column marked T, opposite the number in the column marked C corresponding to the given compression ratio.

To determine the compression pressure corresponding to any initial pressure; multiply the given initial pressure by the number in the column marked P, opposite the number in the column marked C_r, corresponding to the given compression ratio.

C_r	T	P	C_r	T	P
3.	146.89	4.407	4.	162.45	6.498
3.05	147.74	4.506	4.1	163.86	6.718
3.1	148.58	4.606	4.2	165.25	6.940
3.15	149.42	4.707	4.3	166.62	7.164
3.2	150.25	4.808	4.4	167.96	7.390
3.25	151.06	4.910	4.5	169.29	7.618
3.3	151.87	5.011	4.6	170.59	7.847
3.35	152.67	5.115	4.7	171.88	8.078
3.4	153.47	5.217	4.8	173.17	8.311
3.45	154.25	5.322	4.9	174.40	8.546
3.5	155.03	5.463	5.	175.64	8.783
3.55	155.80	5.531	5.1	176.87	9.020
3.6	156.57	5.637	5.2	178.07	9.260
3.65	157.32	5.742	5.3	179.26	9.501
3.7	158.08	5.848	5.4	180.44	9.744
3.75	158.82	5.956	5.5	181.60	9.988
3.8	159.56	6.064	5.6	182.75	10.234
3.85	160.29	6.171	5.8	185.01	10.730
3.9	161.02	6.280	6.	187.22	11.238

133. Temperatures of Combustion of Mixtures of Gas and Air in Varying Proportions. In the following table, the figures at the top of the columns show the proportion of gas to air in the mixture comprising the fresh charge, mixed with the products of combustion left over from the previous explosion in the clearance space of a non-scavenging gas engine.

The figures in the columns give the usual temperatures of explosion.

The figures in the Column marked C_r give the compression ratio.

C_r	1 to 6	1 to 7	1 to 8	1 to 9	1 to 10	1 to 11	1 to 12
	°F	°F	°F	°F	°F	°F	°F
3.	2027	1877	1865	1739	1629	1524	1398
3.1	2060	1912	1895	1767	1656	1549	1421
3.2	2092	1944	1924	1794	1681	1572	1442
3.3	2122	1975	1952	1819	1705	1595	1462
3.4	2150	2004	1977	1843	1727	1615	1481
3.5	2177	2032	2001	1866	1748	1635	1500
3.6	2202	2058	2024	1887	1768	1653	1516
3.7	2225	2082	2046	1907	1786	1671	1532
3.8	2248	2106	2066	1926	1804	1688	1548
3.9	2269	2128	2086	1944	1821	1703	1562
4.	2290	2149	2104	1961	1837	1718	1576
4.2	2327	2189	2139	1993	1867	1746	1602
4.4	2362	2225	2170	2022	1894	1772	1625
4.6	2398	2259	2199	2049	1919	1795	1646
4 8	2422	2289	2225	2073	1942	1816	1665
5.	2448	2317	2249	2096	1963	1836	1683
5.2	2473	2344	2271	2116	1982	1853	1700
5.4	2495	2368	2292	2136	2000	1870	1715
5.6	2516	2391	2311	2158	2016	1886	1729
6.	2554	2431	2346	2186	2046	1914	1755

134. **Usual Exhaust Temperatures and Pressures.** The accompanying table may be used for ascertaining the usual exhaust temperatures and pressures as follows:

To ascertain the exhaust temperature corresponding to any explosion temperature; multiply the given explosion temperature by the number in the column marked T, opposite the number in the column marked E_r corresponding to the given expansion ratio, and divide the product by 1,000. The result will be the absolute exhaust temperature required.

To ascertain the exhaust pressure corresponding to any explosion pressure; multiply the given explosion pressure by the number in the column marked P, opposite the number in the column marked E_r corresponding to the given expansion ratio, and divide the product by 100 The result will be the absolute exhaust pressure required.

E_r	T	P	E_r	T	P
3.	719.22	23.975	4.	659.75	16.494
3.05	715.66	23.464	4.1	654.88	15.978
3.1	712.18	22.978	4.2	650.1[illegible]	15.480
3.15	708.75	22.5	4.3	645.55	15.014
3.2	705.43	22.045	4.4	641.16	14.573
3.25	702.15	21.605	4.5	636.85	14.152
3.3	698.95	21.180	4.6	632.66	13.745
3.35	695.80	20.770	4.7	628.60	13.374
3.4	692.72	20.374	4.8	624.68	13.013
3.45	689.68	19.991	4.9	620.8	12.669
3.5	686.72	19.621	5.	617.03	12.340
3.55	683.80	19.262	5.1	613.37	12.027
3.6	680.94	18.915	5.2	609.81	11.727
3.65	678.14	18.580	5.3	606.34	11.440
3.7	675.36	18.258	5.4	602.95	11.166
3.75	672.66	17.937	5.5	599.64	10.903
3.8	669.99	17.631	5.6	596.41	10.650
3.85	667.36	17.334	5.8	590.15	10.175
3.9	664.79	17.046	6.	584.19	9.787

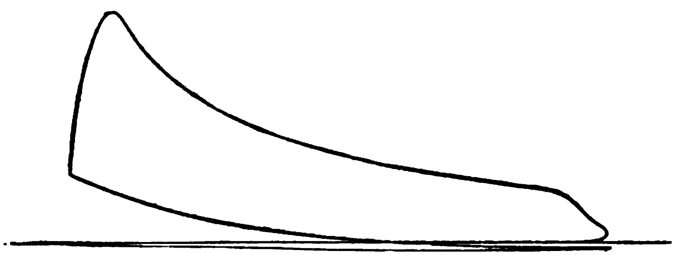


Fig. 32.—Typical Indicator Card.
Fair Performance.
(Paragraph 135)

135. Typical Indicator Diagrams. The indicator diagrams shown in *Figs.* 32, 33, 34 and 35, exemplify the action of a four-cycle gas engine as follows:

Fig. 32, is typical for average performances, the engine developing a moderate amount of power from a fairly strong mixture.

Fig. 33, shows a very good diagram, the nearly vertical explosion line with the high peak coming almost to a point, denotes a strong mixture and quick explosion. The smooth expansion line indicates that there was little or no after-burning or continuation of the combustion as the piston moved forward.

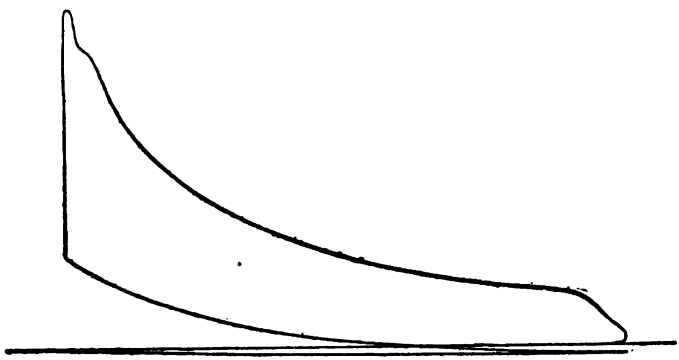


FIG. 33.—TYPICAL INDICATOR CARD.
Good Performance.
(Paragraph 135)

FIG. 34.—TYPICAL INDICATOR CARD.
Poor Performance.
(Paragraph 135.)

Fig. 34, indicates a poor performance, the slanting explosion line without any peak, being the result of a late ignition and slow explosion, due to a poor mixture.

Fig. 35, indicates the following conditions: the vertical explosion line with a high peak denotes a high explosion temperature, but the wavy expansion line may be due either to the vibration of a weak indicator spring, or to the effect of after-burning. See paragraph 90.

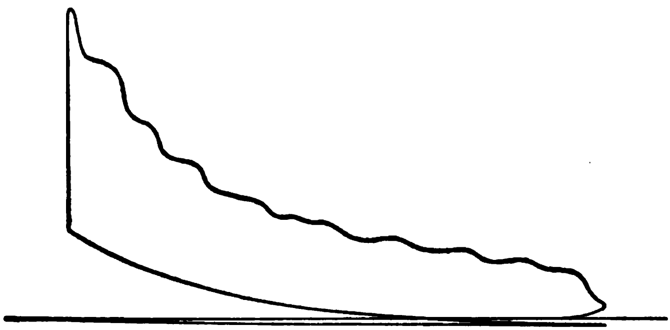


FIG. 35.—TYPICAL INDICATOR CARD
Effect of After-Burning.
(Paragraph 135)

CHAPTER XI.

DESIGN AND CONSTRUCTION.

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136. Mechanical Design. The general design and construction of the various types of gas engine are subject to the same laws and principles as those which form the basis of the best steam engine practice, but all values relating to such features as the weight of fly wheels, shaft diameters, bearing surfaces, crank arrangements, cross sectional area of ports, etc., are suitably modified to fit the peculiar conditions due to the special manner in which the driving power is developed in the cylinder and transmitted through the engine parts under the various cycles of operation.

The variety of structures and mechanisms possible under these conditions is so great, that it is impracticable to formulate any given number of general rules which will bear particular application.

For example: The fly wheels of single cylinder, four-cycle engines require to be made heavier than those of the two-cycle type, and much heavier than those for any type of steam engine, so as to store up sufficient energy from the power stroke to carry the engine through the three idle strokes of the cycle at a uniform speed under a given load, furthermore, two fly wheels are usually employed in order to permit of their size being kept within reasonable limits, and for the purpose of counteracting transverse vibrations.

It is obvious, that as the number of impulses or working strokes in the cycle increases, the weight of the fly wheel can be

materially reduced. An increase of the number of impulses in the cycle of an engine unit may be obtained by the application of the two-cycle principle, or by the multi-cylinder type of construction, and the latter practice can be elaborated to such an extent that four, six, or eight cylinder units, with cranks properly opposed and weighted, may be constructed so as to give a satisfactory uniform torque or turning effort without the use of a fly wheel. This type of construction is particularly applicable to automobile motors, and various types of internal combustion engines used for marine purposes.

The general practice with regard to the design and construction of cylinders and pistons is equally varied, for it is controlled by the quality of the fuel used, the cycle of operations applied, and the characteristic features of the mechanical arrangement in general.

For this reason, the description of the essential features of the various types of standard gas engine, domestic and foreign, is given in the following chapters as fully as practicable, and it will serve to indicate the tendency of the latest practice in the application of general principles to particular cases.

On the other hand, there are certain features which are necessarily common to all gas engines, on account of the inherent characteristics of the internal combustion method of heating. These features relate to the methods employed for cooling the cylinders and other parts which are exposed to high temperatures; to cylinder and piston dimensions; and to the use of special forms of valves, valve gears, governors, and igniters.

137. **Cooling Methods.** The extremely high temperatures attained within the cylinders of gas engines compel the adoption

of some form of cooling arrangement not only in the case of the cylinder itself, but also in connection with the piston and the valves.

This cooling is usually accomplished by providing the cylinder with an outer casing or water jacket, and the piston and valve chambers with water spaces, through which cooling water is caused to circulate continuously when the engine is in operation. This water carries off the heat absorbed by the cylinder walls, piston, etc., thus keeping the temperature of these parts down to a point between 150° and 200° Fahr., or sufficiently low to prevent the burning of the cylinder oil, and the consequent ineffective lubrication of the cylinder.

The continuous circulation of the jacket water can be maintained by one of the three following methods:

1. In the case of small stationary engines, the cool water can be taken from a hydrant, and the hot water issuing from the water jacket allowed to run to waste.

2. A more satisfactory and economical method is to provide a water tank, the height of which is greater than its diameter, and connect it to the engine as shown in *Fig.* 52. After the tank is once filled, it will only be necessary to add a little water occasionally to replace the loss by evaporation.

The circulation is automatically maintained while the engine is in operation by the heating of the water in the water jacket. When this takes place, the hot jacket-water is forced up into the pipe A, and thence to the upper part of the tank by the pressure of the cold tank water, which passes into the water jacket through the pipe B. The valves 81 and 69 are never closed except for draining the water from the jacket and pipes during freezing weather, or for the purpose of dismounting. In such

cases the valves are closed and the water in the pipes and jacket allowed to drain off through the drain cock 2. A vent at C, prevents any possibility of an air lock, and also serves to discharge any vapor that might be generated in the vertical part of the pipe A, thus preventing it from passing into the tank and heating the water therein.

3. In the case of large engines, a small pump D, *Fig.* 51, is properly connected with the pipe B, and being driven from the main shaft of the engine itself, maintains a constant circulation of the cooling water while it is in operation. The hot water is discharged by a sprinkling head E, into a cooling box F, through which it passes to the main tank.

Another cooling method is that in which the cylinder is cooled by the rapid circulation of a current of air. It is not significant in connection with large engines, but it is essential to the satisfactory operation of a bicycle motor, and is valuable in connection with automobiles and small marine motors where the reduction of weight gained by the absence of the cooling water supply is advantageous for various obvious reasons.

The cylinders of air-cooled motors have no water jackets, but are provided with a series of thin circumferential ribs or fins, cast on the outside, or with a large number of metallic spines screwed radially into the walls, thereby greatly increasing the radiating surface. In the case of the bicycle motor, the motion of the machine through the air is depended upon to cool its cylinder down to the proper temperature, but in the case of the automobile motor, a belt-driven fan or propeller is employed for the purpose of maintaining a good circulation of air around the ribs or spines which conduct the heat from the cylinder walls and dissipate it into the atmosphere from their own surfaces.

The Stolp wired tubing for automobiles represents an elaboration of the ribs and spines form of construction, and of the application of the air-cooling method to heated parts other than the cylinder walls.

138. **Cylinder and Piston Dimensions.** The design and construction of the essential features of gas engine cylinders, as described in the preceding paragraph, sufficiently distinguished them from those of steam engines, the former being provided with water jackets to carry off a certain amount of surplus heat, while the latter are incased in non-conducting jackets of lagging, etc., which serve to keep in the cylinders as large a proportion as possible of the total amount of heat admitted into them in the form of steam.

On this account, and in order to enable them to resist successfully the higher pressures suddenly developed by the explosions, gas engine cylinders are usually made much heavier and stronger than those of steam engines. Furthermore, their dimensions for a given horse-power vary for different cycles, piston speeds, and kinds of fuel, and require for their computation the use of some satisfactory empirical formula for mean effective pressure, in connection with the accepted formula for the indicated horse-power of a piston engine, given in paragraph 269.

It is generally accepted, in present practice, that the ratio of the diameter of the cylinder to the length of the stroke lies between the values—$L = D$ to $1.5\ D$, where $L =$ length of stroke and $D =$ bore of cylinder. A stroke equal to twice the diameter, which is quite common in steam engines, is seldom used in gas engines. In the latter, the length of the stroke usually ranges from $1.25\ D$ to $1.3\ D$; the latest practice in marine gas engine

design favors the use of a stroke equal to the diameter, especially in the case of the larger multi-cylinder engines.

In determining the thickness of the cylinder walls, due allowance must be made for reboring, as well as for a sufficient amount of metal to insure stiffness and the making of a sound casting. In order to permit free expansion and prevent distortion from any cause, it is distinctly preferable that the liner or cylinder bore should be made in a separate piece from the water jacket or cylinder barrel. This also permits easy renewal should defects appear.

139. **Clearance Volume.** In computing the cylinder volume by the use of the formula for indicated horse-power, if the values for **E** and **P** are assumed, and **L** expressed in terms of **D**, the solving of the equation for **D** will give the piston displacement, which subtracted from the total volume of cylinder and valve chambers, will give the clearance volume. (See Par. 269.)

140. **Water Jacket.** As a general rule, when **T** represents thickness of the cylinder walls, and **D** the diameter, **T** may be taken as equal to 0.09 **D**, but with very small cylinders this value will give a thickness insufficient for the making of a good casting, an arbitrary allowance being necessary in such cases. As a rule, the depth of the water jacket may be taken equal to 0.1 **D**, measured radially across the jacket.

141. **Piston.** The design and dimensions of pistons vary in the different types of engines according to their cycles, action, and character of service. The piston of a single acting gas engine of any type is invariably of the trunk or tubular pattern, and is connected directly to the crank pin by a short, massive connecting rod of the marine type, which is attached to a crosshead pin in the hollow of the piston.

This arrangement obviates the use of slide bars and crosshead as in the case of the double-acting engine, thereby giving, in this particular, greater simplicity of construction. The length of the piston is usually about twice the diameter of the cylinder, or such that the pressure due to the tangential thrust of the connecting rod is kept as small as possible.

In the case of automobile and marine motors, the best practice makes the length of the piston equal to the diameter of the cylinder, and the length of stroke the same.

142. **Valves.** The admission and exhaust valves are invariably of the poppet type. Slide valves have been used in rare instances, but for many reasons they are absolutely unfitted for use in any type of internal combustion engine. Poppet valves are particularly well adapted for gas engine use on account of the facility with which they can be operated to satisfy the requirements of the various cycles, and their freedom from any liability to expand and stick under the influence of the high temperatures to which they are exposed.

Their dimensions are governed by the diameter of the cylinder and the piston speed. In calculating the areas of the valves, ports and passages, special attention should be paid to making them large enough to keep the velocity of the gas and air through the inlet and admission valves sufficiently low to prevent excessive friction, which, directly or indirectly, results in considerable loss of power. Present practice, in this connection, keeps the inlet flow at about 60 lineal feet per second for automatically operated valves, and 90 to 100 lineal feet per second for those that are operated mechanically, with the flow through the exhaust valve at about 80 feet per second.

143. **Valve Gears.** The general design of valve gearing varies according to the cycle of the engine and the methods of governing and ignition adopted.

The valve gearing of a two-cycle engine is usually very simple, as an impulse occurs during each revolution. Valves are frequently dispensed with, the piston itself serving to control either admission or exhaust, or both.

In the four-cycle engine, only one explosion is realized for

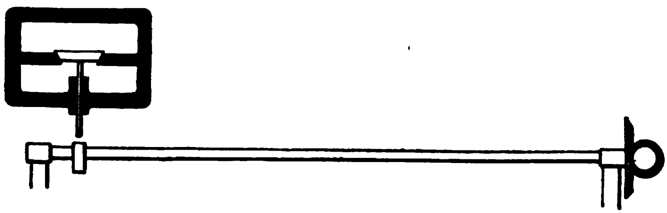

Fig. 36.—Valves Operated by Bevel Gearing. (Paragraph 143)

Fig. 37.—Valves Operated by Spiral Gearing. (Paragraph 143)

every two revolutions of the crank shaft, thereby requiring a more complicated mechanism for the operation of the valves than is the case with the two cycle engine, as each valve must open and close only once in every two revolutions.

This action is usually obtained by means of a secondary or cam shaft driven from the main shaft by toothed wheels geared two to one, which cause the secondary shaft to make one-half

the number of revolutions of the main shaft, hence it is frequently termed the *half-speed shaft.* The secondary shaft may be driven from the main shaft by means of bevel wheels as shown in *Fig.* 36, or by spiral gearing as shown in *Fig.* 37. In either case it is placed horizontally alongside the engine and extends from the main bearing to the valve chest on the cylinder where it operates the valves by means of cams and rock shafts

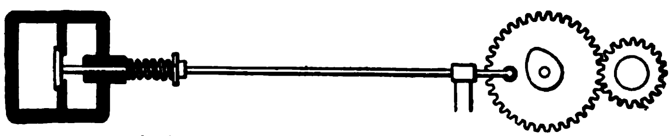

Fig. 38.—Valves Operated by Spur Gearing
(Paragraph 143)

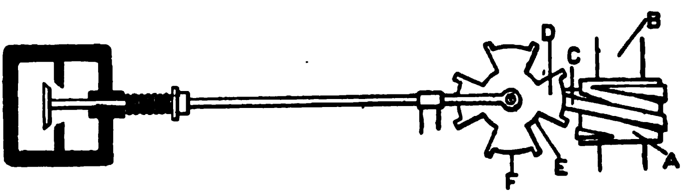

Fig. 39.—Valves Operated by Worm Wheel Cam.
(Paragraph 144)

These methods are among the oldest arrangements employed for this purpose, and possess the great advantage of reducing to a possible minimum the size and weight of all the external moving parts of the engine. These plans also provide independent control of the valves at either end of a cylinder, in a double-acting engine.

Another plan is shown in *Fig.* 38. In this case the secondary shaft is driven from the main shaft by two to one spur gearing, and as it is comparatively short, the entire arrangement is more

efficient and is subject to less friction than those devices which employ either bevel or spiral gears. The valve rod is much longer, however, and the friction greater on account of the greater inertia, than in the others.

144. Eccentric and Cam Arrangements. There are several methods by which the valves and ignition devices may be operated without the use of a secondary shaft. In the arrangement shown in *Fig.* 39, a worm wheel A is mounted on the main shaft B. The middle thread of the worm wheel is swelled out

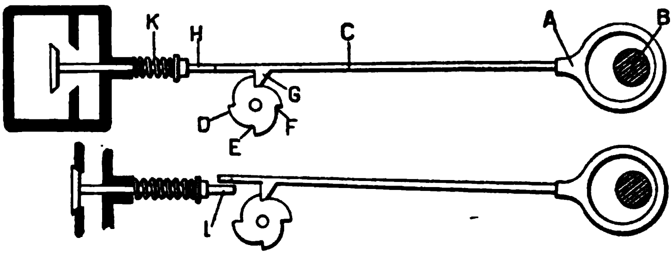

Fig. 40.—Valve Operated by Eccentrics.
(Paragraph 144)

to make a cam C, which engages the teeth of the star wheel carried on the end of the valve rod. The worm wheel turns the star wheel one space for each revolution of the main shaft, but the cam thread of the worm wheel pushes the valve rod only once every other revolution of the main shaft.

The action of the entire arrangement is as follows: when a tooth D of the star wheel is in line with the cam thread C, the cam pushes the valve rod and opens the valve. In the meantime, one revolution of the main shaft turns the star wheel one space and when the cam returns to its former position, it falls

into the space E of the star wheel, and therefore, cannot push the valve rod. It turns the star wheel, however, through another revolution of the main shaft, and when it returns to its original position a second time, it comes in line with the tooth F of the star wheel and again pushes the valve rod and opens the valve.

A simpler contrivance is shown in *Fig.* 40. An eccentric A mounted on the main shaft B, and the eccentric rod C, reciprocate over a ratchet wheel D. The notches in the ratchet wheel are alternately deep and shallow as shown at E and F. The eccentric rod turns the ratchet wheel one notch at each return movement, and causes the pawl G to fall alternately into the deep and shallow notches.

When the pawl falls into a deep notch, the end of the eccentric rod hits the valve stem H, and pushes the valve open. The eccentric rod is then drawn away by the rotation of the main shaft and the valve is re-seated by the action of its spring. When the eccentric rod returns, the pawl falls into a shallow notch, and being thus raised above the level of the valve stem, the eccentric rod misses it, as shown at L, and allows the valve to remain closed.

145. **Balance Weights.** The perfect balancing of a gas engine is a matter of great difficulty, as the intermittant nature of the impulses originating in the cylinder precludes the use of revolving weights driven at the required speed by gear wheels and cams, or the use of variable piston weights on odd crank angles. This is especially true in the case of a single acting engine, which, when properly balanced for horizontal vibrations will be found to be too heavily counterbalanced for vertical movement. The practice in this matter is quite varied and sometimes irrational. Some designs provide for the balancing of the rotating parts and make no allowance for the reciprocat-

ing parts; while in others, one-half of the weight of the reciprocating parts is added to the balance weights of the rotating parts. In some engines the counterweight is placed on the fly wheel near the rim, while in others the rim of the fly wheel on the side next to the crank is cored out.

As a matter of fact, a reciprocating part can be balanced perfectly only by placing another reciprocating mass in such a position that all free couples and free forces are eliminated by their opposed action.

It is obvious, that in the case of a two-cylinder engine this result can be obtained only by placing the axes of the cylinders on a common line so that the inertia forces are directly opposed, thus eliminating the couple which would exist in any two-cylinder opposed crank arrangement. The *vis-à-vis* cylinder arrangement with forked connecting rod, of the American Crossley engine, described and illustrated in paragraph 202, shows a good example of this method of balancing.

In the case of multi-cylinder engines, balancing by opposed cranks is comparatively easy, and becomes still more so with the increase of the number of cylinders. The general principle applicable to such cases consists in the setting of equal cranks at such angles that a given number of central cranks will oppose an equal number of outer cranks. In the case of an odd number of cylinders, as in a five cylinder unit, the central mass is doubled.

A general description of the construction and operation of the various types of governors and igniters will be found in the following chapters.

CHAPTER XII.

GOVERNING AND GOVERNORS.

146. **Methods of Governing.** The general principles of gas engine governing may be conveniently grouped into four distinct methods:

1. The hit-or-miss method in which charges of constant quality and volume are admitted to the working cylinder at variable intervals.

2. The method of qualitative regulation in which charges of constant total volume, but containing air and gas in variable proportions, are admitted to the working cylinder at regular intervals.

3. The quantitative method in which charges of variable total volume, but containing constant proportions of air and gas, are admitted to the working cylinder at regular intervals.

4. The stratification method in which charges of constant total volume, composed of a variable volume of pure air followed by a variable volume of air and gas of constant proportions, are admitted to the working cylinder at regular intervals.

The important factors in gas engine governing are those which affect the mean effective pressure. These may be generalized as follows:

1. The proportion of air and gas, and inert or neutral matter in the mixture which constitutes the charge.

2. The compression pressure attained before ignition.

3. The time of ignition.

4. The piston speed and the weight of the charge admitted to the cylinder.

When the pressures of the air and gas are different, it is practically impossible to maintain a constant ratio of air to gas under a variable load. The use of suction gas producer systems tends to obviate this difficulty as both the air and the gas are taken in at equal pressures by the suction of the piston, and in the case of any engine the same result may be obtained by the use of suitable devices which will supply both air and gas under the same pressure. But even under these conditions, the proportions of the charge to the neutral element will remain the same if the amount of mixture be varied either by the qualitative or quantitative methods.

147. **Hit-or-Miss Method.** In governing a four-cycle engine by the hit-or-miss method, the chance to regulate occurs only once in every two revolutions of the crank shaft, so that from two to five strokes of the piston will follow a shifting of position of the governor before the speed of the engine is affected by the change. For this reason, this method is practically inapplicable to engines employed for driving electric generators for lighting or other purposes requiring a constant current. Furthermore, it entails the great disadvantage of imparting heavy shocks to the reciprocating parts of the engine at every explosion regardless of the load, and requires the use of a much heavier fly-wheel than when the speed is controlled by throttling, in order to prevent excessive speed fluctuations between explosions, when running under light loads. On the other hand, the method is highly economical and affords more reliable ignition at light loads than is usually obtained by the throttling mode.

148. **Qualitative Method.** In this method the governor controls only the admission of gas by throttling or reducing the

area of the gas inlet. Although its application requires only the simplest forms of mechanical arrangements, it possesses the disadvantage of a great liability to miss fire at light loads, and also a tendency towards incomplete combustion at full load or at under load.

The total result of its application is characterized by a general irregularity of impulse, and a lack of ecomony due to a great waste of gas.

149. **Quantitative Method.** In this method, the inflowing mixture of gas and air is either throttled, or cut off entirely by the action of the governor.

The throttling method is the simpler and more satisfactory for smaller engines using either illuminating or natural gas, but it is inefficient at light loads. The cut-off method is more sensitive, though also more expensive for small engines, but it gives a higher economy at under loads. Both methods are, however, open to the serious objection that the final compression pressure is decreased as the load grows lighter, thus reducing the thermal efficiency of the engine, and consequently, the mean effective pressure, a result which is not economical. There is also a tendency to back-firing, late ignition, or failure of ignition, when using lean gas, such as blast furnace gas.

150. **Stratification Method.** This is the most satisfactory method for the governing of large gas engines, and especially for those using lean gases. In its application, pure air is admitted to the cylinder from the beginning of the charging stroke up to a point which is set either forward or backward by the action of the governor, and at which the mixture of air and gas in fixed proportions begins to enter the cylinder and con-

tinues to flow in until the end of the charging stroke. If perfect stratification could be attained, the contents of the cylinder at the end of the charging stroke would consist of a varying volume of pure air next to the piston, with an inversely varying volume of explosive mixture at the other end of the cylinder, and the surface of contact between the two volumes would remain a line of distinct demarcation even at the end of the compression stroke.

This condition, however, cannot be attained in practice as the natural tendency of gases to mix is increased by the act of compression, and varies in extent according to the amount of time available for that purpose.

In an engine making 90 revolutions per minute, this time is less than half a second, and, therefore, it is quite certain that at the instant of ignition the contents of the cylinder will be richest in the compression space at the head of the cylinder and poorest at the piston, a condition which under a constant maximum compression will insure reliable ignition, approximately perfect combustion, and high efficiency at all loads.

151. **Types of Governors.** Each of the methods of governing, defined in the foregoing paragraphs, may be practically applied by means of a great variety of mechanical arrangements which must, however, be designed to suit the cycle of the engine, its valve mechanism, and ignition device.

The various forms of valve mechanisms are fully described in Chapter XI, and the ignition devices in Chapter XIII.

The governors themselves are of a great variety of types, but they may be conveniently grouped into three general classes, pick-blade, centrifugal, and inertia governors.

152. **Pick-blade Governors.** *Fig.* 41, shows a type of pick-blade governor used on a Backus engine governed by the hit-or-miss method. A pendulum device, A, derives its motion from the eccentric rod, B, and actuates a pick-blade, C. At normal speed, the pick-blade hits the notch, D, of the push-blade carried on the end of the admission valve stem, and pushes the valve open at every other revolution of the crank shaft. When the speed increases, the pendulum oscillates more quickly and throws the point of the pick-blade upwards so that it misses the notch and fails to push the valve open, thus cutting off the supply of gas. The normal speed of the engine can be changed while it is in motion by simply adjusting the thumb nut, E, which limits the amplitude of the oscillation of the pendulum, and consequently the vibration of the pick-blade.

153. **Centrifugal Governors.** *Fig.* 42, shows a type of centrifugal governor used on a Foos engine, and operating on the hit-or-miss principle. At normal speed, the blade, A, on the fuel lever, B, operated by a cam on the gear wheel, C, strikes the notched finger D, on the end of the push rod, E, causing the fuel valve to open and admit a charge into the cylinder at each revolution of the cam. As the speed increases, the governor balls, F, move outward, causing the spool, G, to push against the roller, H, carried on the upper end of the governor lever, K. This action causes the lower end of the lever to move inwards and push the notched finger, D, out of its normal position, so that the fuel-lever blade, A, fails to hit it, and thus allows the fuel valve to remain closed.

The fuel supply being thus cut off, the speed decreases and the governor balls return to their original position, releasing the pressure on the lower end of the governor lever and allowing

the notched finger D to resume its regular position under the pressure of a spring.

It will be understood in this connection, that centrifugal fly-ball governors operating on the hit-or-miss principle may be attached horizontally to a transverse secondary shaft as in the foregoing case, or they may be placed vertically at the side of

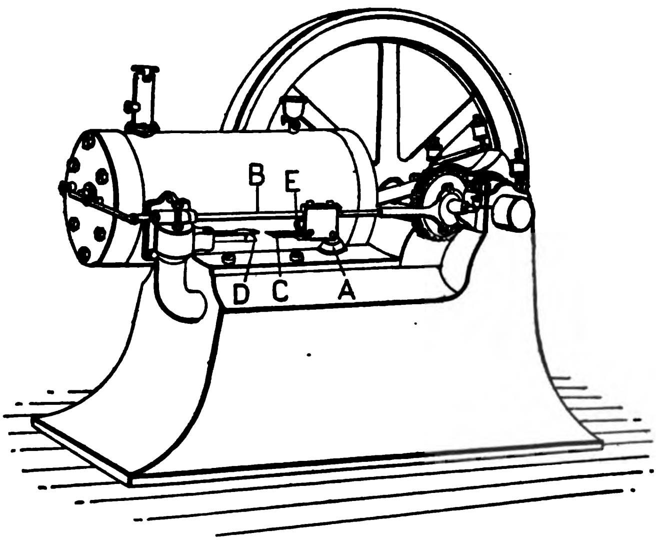

Fig 41.—Pick-blade Hit-or-Miss Governor.
(Paragraph 152)

the cylinder and receive their motion from a longitudinal secondary shaft through the medium of bevel gearing.

An example of the latter arrangement is given in the case of the Otto engine shown in *Fig.* 55, paragraph 193.

In another arrangement, very commonly used, the governor operates the admission valve through the medium of a bell-

crank, one arm of which moves the valve stem, while the other arm carries an impact roller which is capable of sliding on its axle.

The cam on the secondary shaft strikes the roller and raises or opens the valve against the tension of its closing spring.

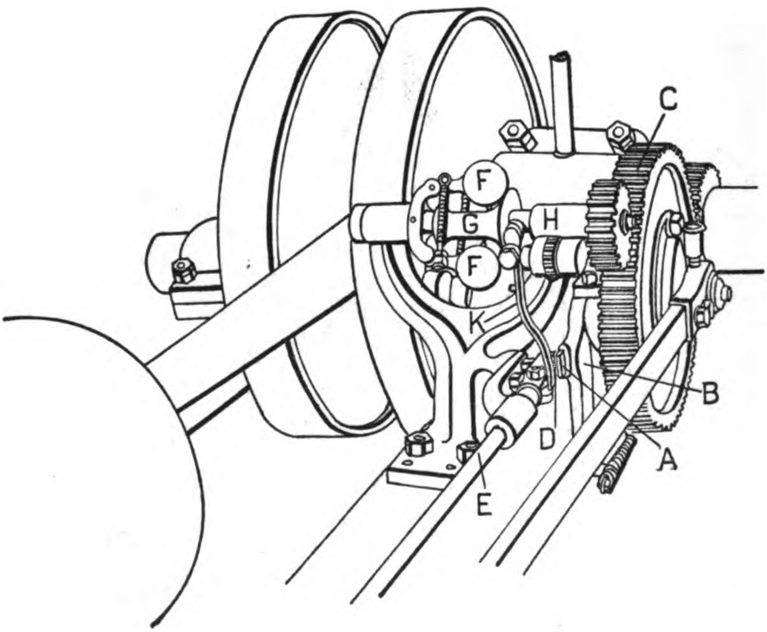

Fig. 42.—Centrifugal Hit-or-Miss Governor.
(Paragraph 153)

When the speed increases, the governor balls move outward, and the roller is shifted along its axle out of reach of the cam, so that the valve remains closed until the speed is reduced to the normal, when the inward movement of the governor balls brings the impact roller back again into line with the cam.

The use of a centrifugal fly-ball governor in connection with the throttling method is shown by *Fig.* 43, which represents the governor arrangement of the Strang engine.

The governor valve-casting is rigidly secured to the cylinder, with the gas opening in line with the air passage, A, leading to the air valve. The gas supply is received through the cock,

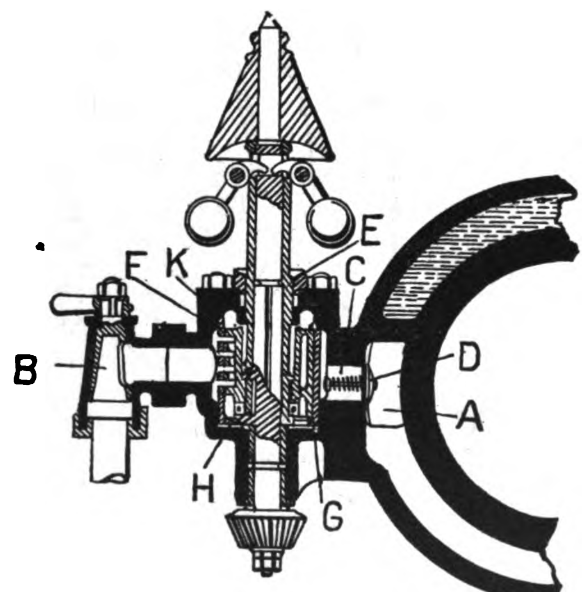

Fig. 43.—Centrifugal Fly-ball Throttling Governor.
(Paragraph 158)

B. The passage, C, leading from the governor into the cylinder is normally closed by the check valve, D, which is held in place by a spring, and opened for the admission of gas into the cylinder by the suction of the piston. This valve also prevents the accidental escape of gas through the air passage when the engine is not running and the supply cock is left open.

The governor valve, E, is inserted loosely in the casing, and is separated from its wall by a liner, F, which leaves an annular space between itself and the wall. A number of ports are located on opposite sides of the liner; they open into the annular space and are separated from each other by a projecting vertical web G, which runs the whole length of the valve, thus completely preventing the effect of the suction induced by the piston from reaching the supply side of the governor valve.

The bottom of the liner is formed into an annular lip, H, on which the governor valve rests when in its normal position. The valve is hollow, of cylindrical cross section, and its exterior shell is provided with a series of ports which correspond to those in the liner.

The inner shell of the governor valve is provided with an annular shoulder which fits into a recess formed by the shoulder on the sleeve, and a nut which engages the lower end of the sleeve. By this arrangement, the governor valve is prevented from moving in a vertical direction independently of the sleeve. When the governor valve is in its normal position, it is supported on the lip of the liner and is not in contact with either the shoulder, the sleeve, or the nut, thus leaving a clear space for purposes of lubrication.

The upward movement of the governor valve is limited by contact with cap, K, and the valve is prevented from having a rotary movement by the lugs, at the lower end of the cap, which project through an opening in the valve and serve to keep its ports always in line with those in the liner.

The sleeve is feathered to the spindle of the governor so as to permit of both rotary and longitudinal movement. The lower end of the sleeve rests upon a collar on the spindle, the upper

end being provided with two lugs to which the arms carrying the governor balls are pivoted.

The governor spindle receives its motion through bevel gearing from the secondary shaft, and diminishes or increases the port openings in the valve according to the increase or decrease of the speed of the engine.

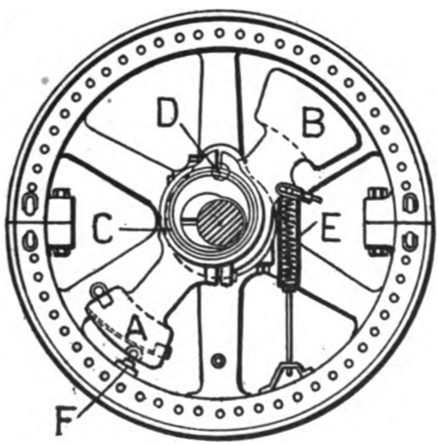

Fig. 44.—Inertia Governor.
(Paragraph 154)

Centrifugal governors may also be attached directly to the fly-wheels or to the crank shafts. In both cases the centrifugal action of the governor-weights tends to shift the position of an eccentric across the center of the crank shaft. Illustrations of several examples are given in connection with the engine descriptions in the following chapters.

154. **Inertia Governors.** *Fig.* 44, shows the general arrangement of the Rites governor. The weights, A and B, are

balanced on the center line of the shaft arm which is attached to the eccentric, C, and pinned to the fly-wheel or pulley at D. The spring, E, holds the weights in normal position, their range of motion by differential momentum due to the variable speed of the engine being limited by the stop, F, on the rim of the pulley.

The governor may be adjusted in three different ways to satisfy the varying conditions of speed and pressure.

1. By changing the tension of the spring.

2. By shifting the point of attachment to the governor arm and thereby changing the leverage.

3. By adding weights to the arm, which is usually provided with panelled recesses for that purpose.

The action of a modified form of this governor is fully described in paragraph 201.

CHAPTER XIII.

IGNITION AND IGNITERS.

155. **Methods of Ignition.** The charge in the cylinder of an internal combustion engine may be ignited by any one of the four following methods:

1. By means of a naked flame.

2. By means of a metallic surface having a high temperature.

3. By the spark of an electric arc.

4. By raising the temperature of the charge to its point of inflammation by compression.

The naked flame method is practically obsolete, and the hot surface or hot tube method nearly so, except in the case of some types of oil engine. Yet many of the makers of standard engines, both domestic and foreign, are always prepared to furnish the hot tube device with any type of gas, gasoline, or oil engine so desired. The electric method is the one most extensively used, and is rapidly replacing all others with the exception of the method of ignition by compression, which is the distinguishing feature of certain types of oil engine.

156. **Moment or Point of Ignition.** The point of ignition is the most important factor in the application of any method or device used for this purpose. For proper ignition, the moment at which the charge is ignited, and which corresponds to a certain point in the cycle of operations, should be neither too early nor too late relatively to the ending of the compression and the beginning of the power strokes.

When the moment of ignition occurs too early, the maximum pressure of the explosion is reached before the end of the compression stroke, thus retarding the motion of the piston, increasing the friction on the crank pin, and consequently reducing the brake horse-power.

When the moment of ignition occurs too late, the mean effective pressure is reduced, and consequently the brake horse-power also.

The highest efficiency is obtained by adjusting the point of ignition to suit the amount of compression, and the speed of the engine.

As an interval of time, no matter how short, must elapse between the moment of ignition and the moment of maximum pressure in order to prevent the delivery of a dead blow on the piston, the moment of ignition should occur immediately after the crank passes its inner dead center at the end of the compression stroke.

Furthermore, as the time of combustion or the interval of time between the moment of ignition and the moment of maximum pressure is not affected by variations in the speed of the engine; in order to obtain complete combustion and a resultant maximum pressure at the beginning of the power stroke, the moment of ignition should occur later for slow speed, and earlier and earlier as the speed increases.

157. **Hot Tube Igniter.** The hot tube consists of a short tube of metal or porcelain which is maintained at a dull red heat by contact with a gas flame, and which is attached to the engine cylinder in such a manner, that a portion of the explosive charge is forced into it, and, being ignited by contact with the hot walls of the tube, inflames the whole charge.

In the ordinary arrangement, the time of ignition depends upon the degree of compression. The products of combustion

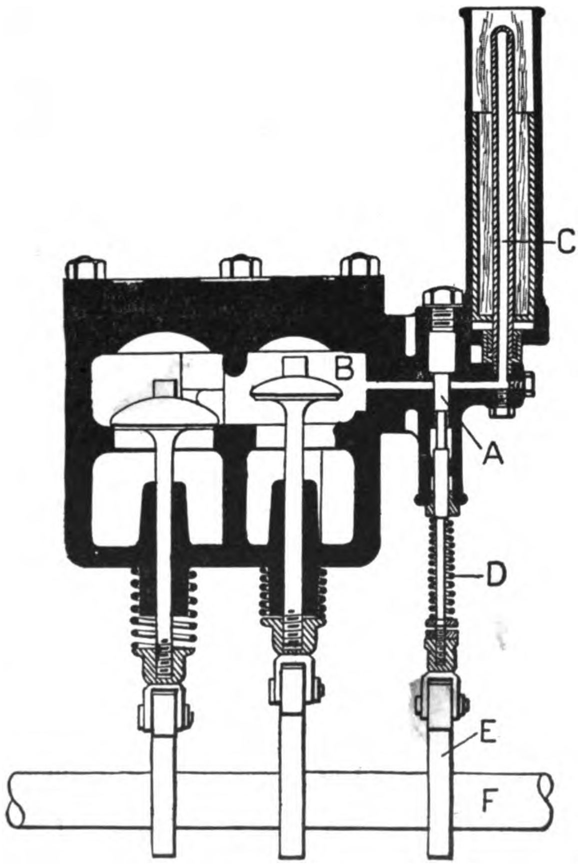

Fig. 45.—Hot Tube Igniter. (Timing Valves.)
(Paragraph 158)

remain in the tube and mix with the succeeding fresh charge, so that varying degrees of compression cause ignition at different

points of the piston stroke or cycle of operations. Under these conditions, the moment of ignition becomes later and later as the amount of compression decreases, until the compression becomes so weak that there is a failure to ignite.

For this reason, ignition by hot tubes is not satisfactory in the case of engines governed on the throttling principle, as the throttling of the charge always tends to diminish the pressure of compression.

158. **Timing Valves.** *Fig.* 45, shows a modification of the hot tube arrangement which is more exact and satisfactory. In this case, a valve, A, commonly called a timing valve, is interposed between the admission valve chamber, B, (communicating with the clearance space of the cylinder) and the interior of the hot tube, C. This valve is normally held closed by the spring, D. When the piston reaches its inner dead point at the end of the compression stroke, a cam, E, on the secondary shaft, F, opens the valve and allows a portion of the compressed charge to pass into the hot tube where it ignites. The timing valve is held open throughout the power and exhaust strokes, thus permitting the products of combustion to be carried out of the tube with the exhaust.

159. **Disadvantages of Hot Tubes.** Some of the dangers and disadvantages of using hot tubes are as follows:

1. The necessity for maintaining an open flame outside the cylinder is extremely hazardous in some localities, and is especially dangerous in the case of a gasoline engine.

2.. Uncertainty of the moment of ignition on account of variable compression.

3. Blowing-by or leakage at the piston rings, and consequent reduction in the amount of compression.

The application of the hot tube or hot head method in the case of an oil engine is illustrated by *Fig.* 114, paragraph 236, which shows the Meitz and Weiss igniter ball arrangement.

160. Electric Ignition. The most flexible method is that in which the charge is ignited by means of an electric spark, the current being derived from various sources of electrical energy.

The spark itself may be created in a number of ways, depending upon the mechanical construction of the igniter devices employed.

These devices are made in many forms, but may be grouped in two general classes, the make-and-break igniters, and the jump-spark igniters.

161. Make-and-Break Igniters. These devices may be divided into two general types, the hammer-break, and the wipe-contact igniters.

Both types employ a low tension current which cannot jump across the smallest kind of a gap in the circuit. Therefore, in order to produce a spark, it is necessary to first close the gap by metallic contact, and then separate the contact points quickly, by mechanical means, while the current is flowing through them.

Fig. 46, shows the general arrangement of a hammer-break igniter. It consists of two metallic terminals, A and B. The terminal, A, is mounted on the movable shaft, C, while the terminal, B, is stationary and insulated from the cylinder wall by the lava bushing, D. A suitable cam rod attached to the crank, E, provides the means for rocking the terminal, A, so as to bring it in contact with the terminal, B, and then quickly separate the terminals for the production of the spark. The helical

spring, F, provides a semi-flexible connection between the shaft, C, and the crank, E. The contact points of the two terminals are tipped with two small pieces of platinum, G and H, and both terminals are mounted in the removable plug, K, which is usually inserted through the walls of the cylinder head, so that the igniter points extend into the compression space of the cylinder.

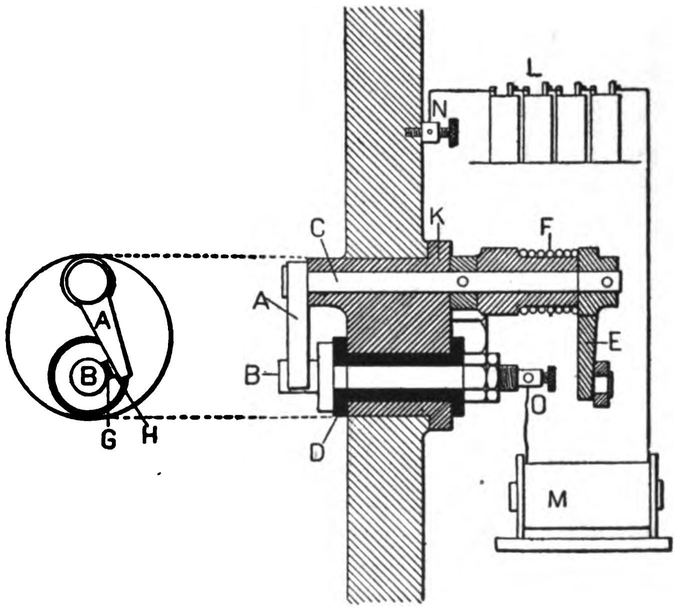

Fig. 46.—Hammer-Break Igniter.
(Paragraph 161)

The electrical equipment consists of a battery, L, and an inductive resistance or spark coil, M, with wire connections at N and O.

When the terminals are brought together, the circuit is closed through the battery and the spark coil, and when the terminals

are quickly separated, the self-induction of the spark coil causes the bright spark to pass between them and ignite the charge.

Fig. 47, shows the general arrangement of a wipe-contact igniter. It consists of two independent electrodes, the stationary electrode, A, and the movable electrode, B. When the latter is revolved by the motion of the igniter rod, C, the revolving

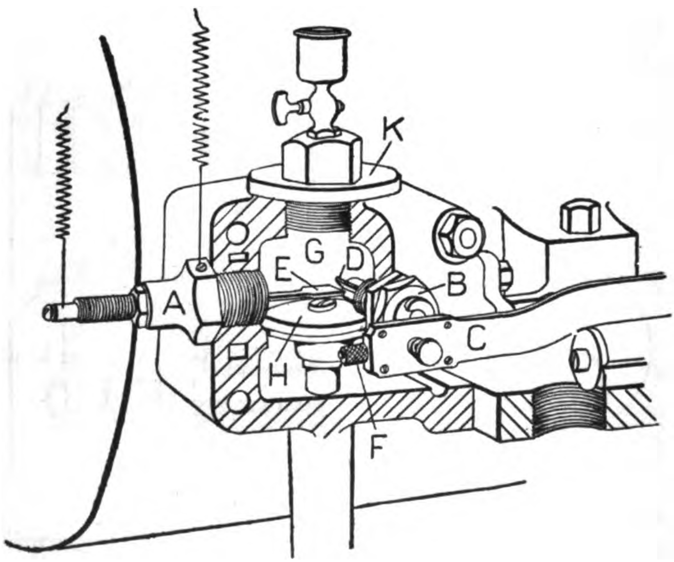

Fig. 47.—Wipe Contact Igniter.
(Paragraph 161)

blade, D, is brought into contact with the spring, E, at each rotation and produces the spark. In this arrangement the break is more effective than in the hammer-break-type, and gives a larger spark with a given battery capacity, while at the same time, the wiping contact of the two parts prevents the accumulation of burnt carbon or scale on their edges, and thus serves to

keep the contact surfaces bright and clean. On the other hand, it possesses the drawbacks incident to the use of a spring which is exposed to the extremely high temperatures developed within the cylinder. The use of flat springs is particularly disadvantageous as it is very difficult to temper them uniformly, and they are consequently liable to break without warning. Furthermore, the wear of the electrodes is excessive.

The moment of ignition can be adjusted while the engine is running by turning the thumb screw, F, on the end of the igniter rod, and this screw is used also to retard the impulses at starting, thus preventing the engine from moving backwards.

The igniter is located in the inlet chamber, G, directly over the head of the admission valve, H, and either one of the electrodes can be reached for inspection or removal, independently, by simply removing the cap, K.

162. **Jump-Spark Igniter.** The various forms of these igniters employ a high tension current. A secondary coil of fine wire is wound around the primary spark coil, which upon making and breaking the circuit will generate a current of high voltage.

Fig. 48, shows the general arrangement. Both igniter terminals, A and B, are stationary, and are mounted in a sparkplug, C, of insulating material, usually of lava or porcelain. These terminals are connected to the secondary terminals, D and E, of the induction coil, and the primary terminals, F and G, of this coil are connected to the battery, H, at the moment of ignition by the contact cam, J, on the secondary shaft, K. The making and breaking of the circuit generates in the secondary coil a high tension current which jumps the perman-

ent gap, L, between the terminals, A and B, and causes a spark every time the circuit is broken.

163. Vibrator or Trembler. In many arrangements, especially those designed for high-speed engines, the primary circuit of the coil includes a vibrator or trembler, M, which insures the ignition of the charge by causing a succession of sparks to jump the gap between the igniter terminals while the circuit closing cam is in contact with its brush.

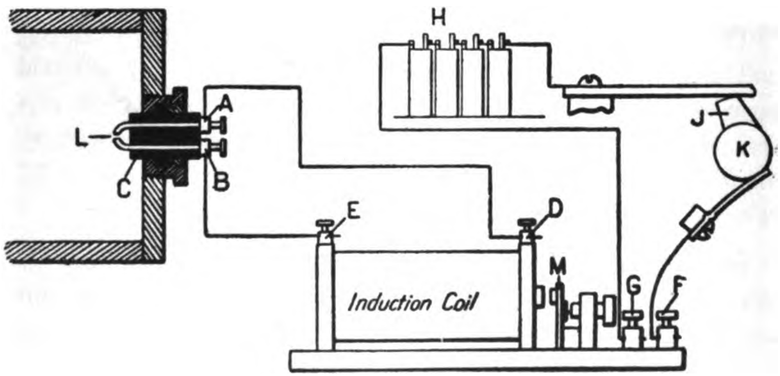

Fig. 48.—Jump Spark Igniter.
(Paragraph 162)

The principal advantages of the jump-spark method are the absence of moving parts and springs within the cylinder, and the simplicity of the mechanism. The principal disadvantage lies in the liability to short circuiting, that is, the gap between the terminals is liable to become connected by an accumulation of carbon on the surface of the insulating plug, thereby allowing the high tension current to pass through without jumping the gap, and consequently resulting in a failure to ignite.

164. Igniter Dynamos and Magnetos. Although the various methods of electrical ignition are far superior to all others, their weakest point is the source of the current. Heretofore, chemical or storage batteries have been employed for this purpose, but they are greatly affected by low temperatures, and faulty ignition is often due to the temporary polarization of dry batteries.

In order to obviate these difficulties, the present tendency is to generate the current mechanically by the use of dynamos or magneto-electrical machines.

The dynamos are of two distinct types, self-exciting and magneto dynamos. Their armatures are usually driven at a speed ranging from 1,500 to 2,500 revolutions per minute, by belt or friction drive from the main shaft of the engine, or from the line shaft, and generate a current ranging from 5 to 10 volts.

Their use obviates the necessity of frequently renewing exhausted batteries, and, in some cases, the use of an induction coil, the dynamos being capable of generating a current of sufficiently high potential to force a spark across the gap between the igniter terminals.

One objection to the use of dynamos is that they do not operate until the engine has been started, thus requiring the use of some auxiliary apparatus in the form of primary or storage batteries for starting. This difficulty is, however, satisfactorily overcome by the adoption of systems of wiring which provide for taking the current for ignition from a storage battery at all times, while the current from the dynamo is used for recharging the battery. This method insures a constant voltage, and thus obviates the necessity for adjusting the vibra-

tor of the jump-spark coil when the current is switched from dynamo to storage battery, or *vice versa.* Furthermore, it gives the operator two possible sources of current, thus enchancing the reliability of the ignition.

165. Wiring Dynamo or Magneto for Make-and-break Ignition. For make-and-break ignition, the general plan of wiring or connection is the same for both dynamos and magnetos, but it requires some modification in the case of the jump-spark.

Fig. 49, shows the plan usually employed. The generator may be placed on a low stand on the floor and connected by belt with the fly wheel, or, if it is to be driven by a friction pulley, it may be placed on some part of the engine frame so that the pulley will just touch the fly wheel when the generator is in the middle position.

If the generator is a dynamo, it is usually connected to run right-handed or clockwise, but if it is desired to run it in the opposite direction, this may be accomplished by crossing the leads going to the two brush holders from the field coils.

In the case of a magneto, it makes no difference in which direction the armature is revolved.

The wires leading from the generator and from the battery should be connected with the engine through the spark coil and the switch as shown in the figure.

Engines of three-horse power or less do not require batteries for starting, as a few rapid turns of the fly wheel by hand will produce a spark of sufficient intensity to ignite the charge. Engines of more than three-horse power usually require starting batteries composed of six or eight dry battery cells.

To start the engine, throw the lever of the switch so as to connect the battery with the engine, and as soon as the engine begins to run steadily, throw the switch lever so as to connect

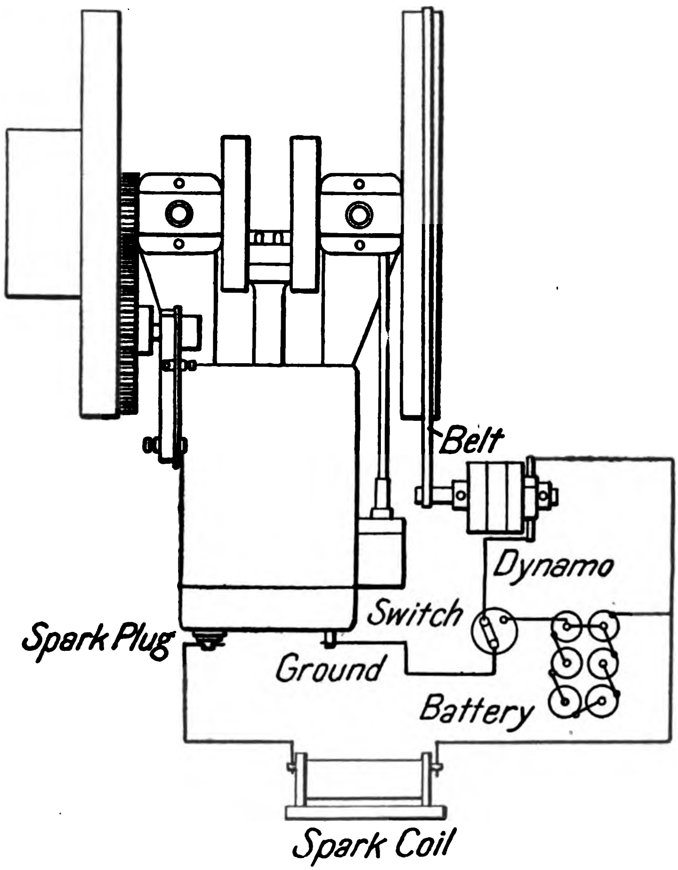

Fig. 49.—Wiring Dynamo or Magneto for Make-and-Break Ignition. (Paragraph 165)

the dynamo or magneto with the engine, and cut the battery out of the circuit.

When the engine is not running, leave the switch lever connected to the generator, and never throw the switch on the battery except for the purpose of starting.

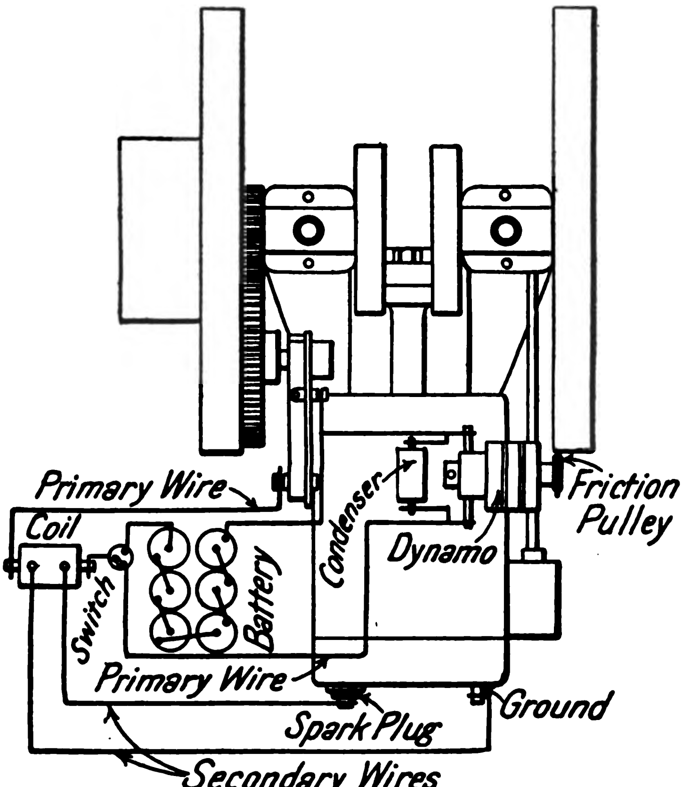

Fig. 50.—Wiring of Dynamos and High-Tension Magnetos for Jump Spark Ignition.
(Paragraph 166)

The oil cup should be filled with light, clean engine oil, at least once a month, and the commutator should be cleaned occasionally with a small piece of fine sand paper.

166. Wiring of Dynamos and High-tension Magnetos for Jump Spark. *Fig.* 50, shows the general plan of connection for a dynamo driven from the fly-wheel by a friction pulley.

The speed of the dynamo should be the same as that indicated on its name plate and it should be connected to run clockwise or right-handed, when viewed in the direction of the commutator.

The wires from the dynamo and battery should be connected to the engine through the switch and primary coil, and the wires from the secondary coil should be connected to the spark plug and the engine as shown in the figure.

The engine is started by means of the battery, and its operation continued with the current from the dynamo in the same manner as described in the preceding paragraph.

The brushes of the dynamo should press firmly on the commutator but not so as to bind, and if at any time the dynamo ceases to generate current, the commutator should be cleaned with a piece of sand paper.

When the dynamo is driven by means of a friction pulley, the latter should be arranged to just touch lightly against the fly wheel, as too much pressure tends to destroy the leather. Usually, the dynamo is furnished with a tension spring which serves to press the friction pulley against the fly wheel, thus obviating the necessity for using injurious tightening screws.

167. Igniter Points. The successful application of electrical ignition methods depends upon the effective action of the battery, the dynamo, or magneto, the spark coil, and the igniter points.

The igniter points should be good electrical conductors, and at least one of them should be effectively insulated from the metal of the engine.

They may be made of iron or hardened steel, German silver, platinum, or an alloy of platinum and iridium.

Soft steel points are more suitable for make-and-break ignition than for the jump-spark. In the former, the contact keeps them clean and produces a satisfactory spark for a much longer period than in the latter.

The principal advantage of iron or steel points is that they can be easily and cheaply renewed.

In fitting them, a small hole is drilled in the igniter part which holds the point, and the new point is placed in it and riveted in the proper position. In some cases, the hole is threaded and the new point screwed in and adjusted by a slotted head provided for this purpose.

Iron and steel points are, however, very liable to rust under moist atmospheric conditions, especially when the engine is not in constant use, and furthermore, they are liable to corrode under the action of the sulphur always present more or less in fuel gas. Both conditions tend to render the ignition uncertain if not impossible. Under such circumstances, it is advisable to use German silver points, or one point of German silver, and the other of steel, the latter being placed on the movable electrode.

Hardened steel is generally employed for the wiping parts of wipe-contact igniters, in order to enable them to withstand the excessive wear due to the wiping action, and such parts are usually so arranged that they can be readily adjusted to take up the wear.

The material most extensively used for igniter points, and one that works equally well on both make-and-break and jump-spark systems, is platinum and an alloy of platinum and iridium. Igniter points of these metals are not oxidized at any

temperature occurring within the engine cylinder, and are not subject to corrosion by any acid in gaseous form; while the alloy being much harder than the pure metal is much more satisfactory, and although more expensive, is nevertheless widely used.

The disadvantage of using any of them lies in the cost, the difficulty of attaching them to the electrodes, and their tendency to honeycombing. The last named condition usually gives a spluttering spark which makes the ignition uncertain at all times, and very often there is entire failure to ignite the charge.

168. Conditions for Reliable Action of Igniter Points. The reliable action of igniter points depends upon the following principal conditions:

1. At least one of the points should be effectively insulated from the engine to the source of electrical energy, and great care should be taken to prevent the current from passing from one igniter terminal to the other in any manner whatsoever except through the igniter points.

2. In make-and-break igniters, the faces of the points should be kept smooth, so as to insure good contact, and they should also be kept clean and free from deposits of grease, which by insulating them, will prevent the production of a spark.

3. Care should be taken against over lubrication, and the use of too rich an explosive mixture, so as to prevent insulating deposits on or about the points.

4. Corroded points should be carefully cleaned with a file, care being taken not to shorten the points to such an extent that they will not come in contact at all, or break contact too late and thereby fail to give a spark at the proper moment of ignition.

5. When the points are made of platinum, or an alloy of platinum and iridium, cleaning by filing is very expensive, as the points become worn down in a very short time. A more economical method of cleaning such points, especially when they are somewhat worn and pitted, is to use gasoline, and then punch them into the proper shape with a small cup punch.

6. In jump-spark igniters, the distance between the points ought not to exceed one-eighth of an inch, and the direction of the current ought to be changed about every two days, in order to prevent the rounding of the contact surfaces of the points by the deposits they receive from each other. This can be accomplished by simply changing the wires from one binding post to the other.

169. Ignition by the Heat of Compression. The method of igniting the charge by raising its temperature to the point of inflammation by compression is fully described in its application in the case of the Diesel engine, paragraph 239.

CHAPTER XIV.

INSTALLATION AND OPERATION.

170. **General Arrangement.** *Figs.* 51, and 52, show the relative positions of the motors and the accessory apparatus in a gas engine, and a gasoline engine, installation, respectively. It is obvious that the general arrangements thus shown may be deviated from in minor details for the sake of convenience, or such changes may be necessary on account of the peculiar structure of a particular engine.

It is equally clear, also, that in the case of all installations, the connections between the motor and its accessories should always be made in such a manner and the accessories themselves so placed, as to give the most efficient service in the operation of the engine.

In this connection, the principal points which require careful consideration are the following:

171. **Location.** The engine should be erected in a room as free from dust as possible, for the efficiency and life of an engine depend largely upon its being kept clean. The room should be well lighted, and care should be taken not only to place the machine at such a distance from the walls that all of its parts are easily accessible, but also to locate it in such a position relative to the shafting or machinery to be driven, that it will not be necessary to use a crossed driving belt.

172. **Foundation.** Engines employed for permanent service should never be bolted directly to a floor, as more or less trouble will be experienced from vibrations, but they should be set on properly built foundations of brick, stone, or concrete. The top plan of the foundation should conform to the dimen-

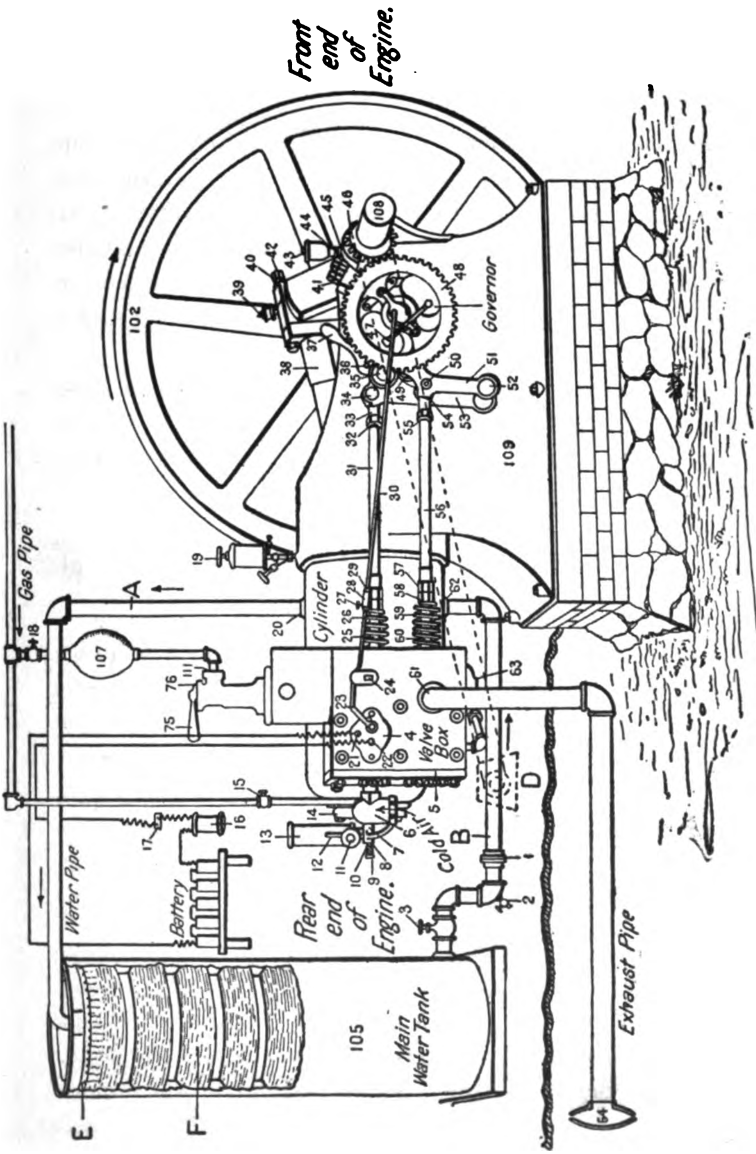

Fig. 51.—Gas Engine Installation.
(Paragraphs 187, 170, 177.)

Names of Engine Parts Corresponding to the Numbers on Figure 51.

1—Union.
2—Air Cock and Globe Valve.
3—Globe Valve.
4—Spark Igniter Plate.
5—Valve Chamber Plate.
6—Air Valve.
7—Timing Valve Casing.
8—Timing Valve.
9—Timing Valve Nut.
10—Timing Valve Spring.
11—Burner.
12—Nickel Alloy Tube.
13—Chimney.
14—Cylinder End Plate.
15—Globe Valve or Stop Cock.
16—Spark Coil.
17—Switch.
18—Globe Valve or Stop Cock.
19—Lubricator.
20—Waterpipe Connections, Overflow.
21—Set Screw
22—Insulated Electrode.
23—Trip of Spark Igniter.
24—Guide and Roller.
25—Receiving Valve Stem.
26—Receiving Valve Spring.
27—Set Screw.
28—Sleeve.
29—Lock-Nut.
30—Igniter Rod.
31—Side Rod.
32—Lock-Nut.
33—Long Rocker-arm Knuckle.
34—Long Rocker-arm Knuckle Pin.
35—Long Rocker-arm Roller and Pin.
36—Pin holding Trip.
37—Trip.
38—Connecting Rod.
39—Connecting Rod Lubricator or Grease Cup.
40—Connecting Rod Brasses.
41—Pillow Block Cap, Studs and Nuts.
42—Connecting Rod Studs and Nuts.
43—Pillow Block Lubricators or Grease Cups.
44—Position of Exhaust Cam when Engine is ready for starting.
45—Pillow Block Cap.
46—Crank Shaft Gear.
47—Split Nut.
48—Gear Wheel on Governor.
49—Short Rocker-arm Roller and Pin.
50—Short Rocker-arm Pin.
51—Short Rocker arm.
52—Rocker-Arm Stud and Nut.
53—Long Rocker-arm.
54—Short Rocker-arm Knuckle.
55—Lock-Nut.
56—Side-Rod.
57—Side-Rod Sleeve.
58—Lock-Nut.
59—Exhaust Valve Spring.
60—Exhaust Valve Stem.
61—Exhaust Pipe Connection.
62—Water Pipe Connection.
63—Air Port.
64—Muffler or Silencer.
75—Gas Valve Handle.
76—Dial Plate.
102—Fly Wheel.
105—Water Tank.
107—Gas Bag.
108—Crank-Shaft.
109—Bed Plate.
111—Gas Pipe Connection.

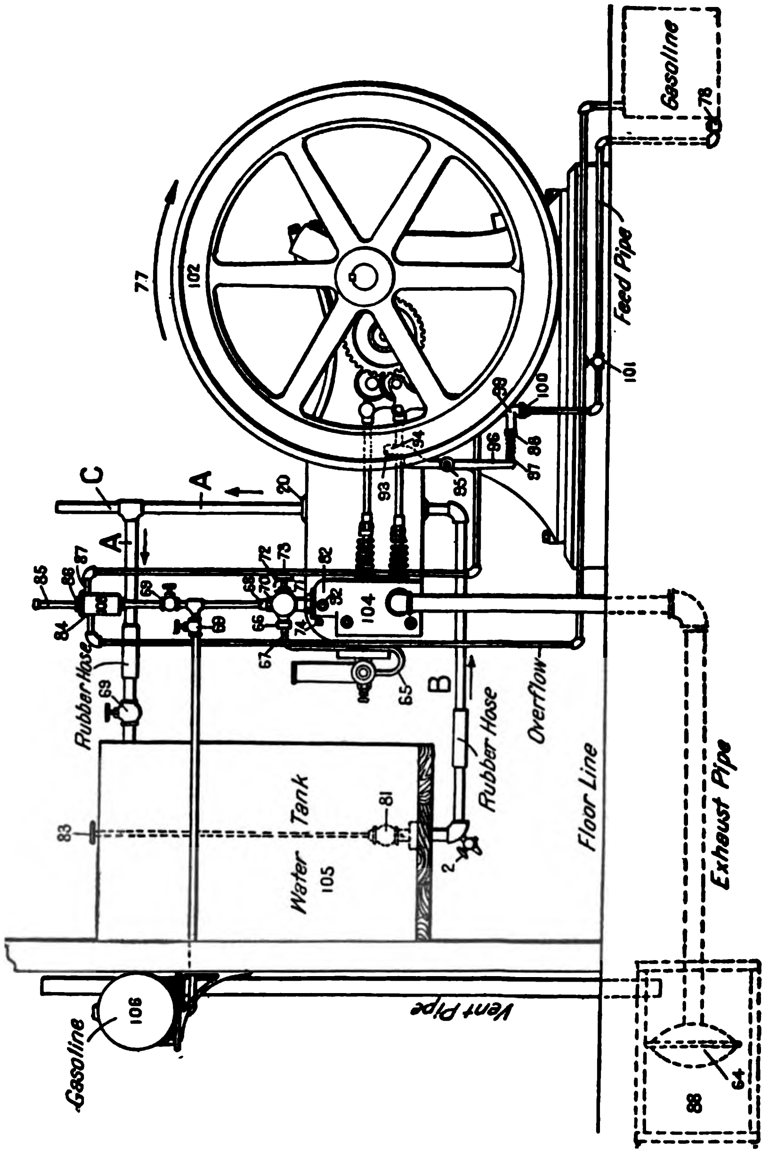

FIG. 59.—GASOLINE ENGINE INSTALLATION.
(Paragraphs 187, 170, 177.)

Names of Engine Parts Corresponding to the Numbers on Figure 52.

2—Air Cock and Globe Valve.
20—Water Pipe Connection, Overflow.
64—Muffler or Silencer.
65—Burner Pipe.
66—Packing Nut.
67—Short Ferrule.
68—Long Ferrule.
69—Globe Valve.
70—Packing Nut.
71—Dial Plate.
72—Dial Pointer.
73—Needle Valve and Handle.
74—Set Screw.
77—Arrow, Direction of Normal Revolution.
78—Check Valve.
81—Shut-off Valve Inside of Water Tank.
82—Disc Gas or Gasoline Valve inside of Valve Box.
83—Shut-off Valve Handle.
84—Overflow Pipe Connection.
85—Nipple in top of Gasoline Cup.
86—Top of Gasoline Cup.
87—Feed Pipe Connection.
88—Underground Muffler Box.
92—Bull's Eye or Nut.
93—Set Screw.
94—Side Rod Lug.
95—Pump-arm Stud.
96—Pump-arm.
97—Pump Plunger and Spring.
98—Packing Nut.
99—Pump.
100—Pump Nut.
101—Globe Valve.
102—Balance Wheel or Fly Wheel.
103—Gasoline Cup.
104—Valve Box.
105—Water Tank.
106—Gasoline Tank.

sions of the engine base. The depth and form below the ground will vary with the character of the soil, being more splayed toward the bottom in light and yielding soil than in solid ground. The depth will vary according to the weight of the engine, or according to its power. In general, the following depths will be satisfactory, 35 inches below the floor level for engines up to 5 horse-power, 45 inches for engines up to 10 horse-power, 65 inches for engines up to 25 horse-power.

As a rule, the foundation bolts should reach down to within one foot of the bottom of the foundation. They should be placed in pieces of metal piping having an inside diameter one-half inch larger than the diameter of the bolts, so as to compensate for any slight deviations in the distances between them, either in the foundation or in the engine frame.

Furthermore, when the engine is finally bolted down, great care should be taken to tighten the bolts evenly, otherwise the frame will be strained, and the main journals thrown out of line, with the result that they will become heated.

Before keying the fly-wheel on the crank shaft, the frame should be levelled up and tightened down, so as to indicate whether the crank moves freely in every position. When the caps over the main bearings are screwed down tight, the throw of the crank shaft ought to drop by its own weight. A failure to do so indicates that the top of the foundation is not level. In this case it will be necessary to level the engine by the use of wooden wedges placed between the engine bed and the top of the foundation. All level measurements should be taken from the secondary shaft and the main shaft.

173. **Inclination of Engine.** In erecting a horizontal engine, always incline the cylinder towards the crank shaft. If

the cylinder inclines towards the rear, lubricating oil will accumulate in the combustion chamber and cause serious trouble.

174. **Fly-wheels and Keys.** Fly-wheels should always be carefully handled, as rough usage such as rolling them down steps, etc., is very liable to damage the turned surface. When keying them on the shaft, care should be taken to use the proper keys in the correspondingly marked key ways, and in driving them into place both should be driven at the same time, so as to avoid the forcing out of the wheel from its true position by either one of the keys.

175. **Crank Shaft and Gear Wheel.** When the crank shaft is placed in its bearings, care should be taken to see that its pinion matches with the spur or bevel wheel so as to bring the tooth marked O in one wheel into the space similarly marked on the other.

176. **Valve Setting.** The O marks on the wheels indicate the shop setting. They come together on all two to one gears every other time, and on all one to one gears every time the crank reaches its inner dead center. This system of marking is applied to all toothed wheels used on an engine.

In a multi-cylinder engine, care should be taken to set the admission cam-shaft gears so that all the marks will come together simultaneously when the center crank reaches its inner dead center. On the other hand, if by mistake, the setting is such that the exhaust cam-shaft gears come together when the crank reaches one inner dead center, and the admission or inlet cam-shaft gears come together at the following inner dead center, it will be impossible to start the engine.

177. **Cooling-Water Connections.** All matters relating to

the supply and circulation of cooling water will be found fully described in paragraph 137, and Chapter XXV.

178. Exhaust Pipe, and Silencer or Muffler. The extension of the exhaust pipe will vary according to local conditions, and the kind of silencer or muffler employed. In all cases the exhaust gases should be carried through the silencer into the open air, avoiding a waste-pipe extended above the roof of the building if possible. This pipe should never be turned into a flue, chimney, or drain, unless the pipe is continued through their entire length. Care should be taken to avoid bends or elbow joints, and long horizontal sections, which tend to produce condensation and thus develop back pressure, which will ultimately stop the engine.

179. Valve Gears, Governors, and Igniters. The various forms of valve gear arrangements, governing mechanisms, and igniter devices, and instructions relating to their construction, attachment, and operation, will be found in Chapters XI, XII, and XIII.

180. Conditions for Successful Operation. The successful operation of a gas engine depends upon four important conditions,—the proper mixture of the fuel and air, the proper amount of compression, the correct timing of the ignition, and effective lubrication.

When once started, the action of a gas engine is practically automatic, and everything being in proper adjustment, it will continue to run as long as the supply of gas and air, electric ignition current, cooling water, and lubricating oil are not interrupted. It is a serious mistake, however, to think that one of these engines can be started, stopped, or operated for an indefinite length of time without any attention being paid to it except to periodically open and close a few cocks and valves.

Before an engine leaves the factory, it is always operated and tested under certain given conditions, and adjusted to run in those circumstances in the most satisfactory manner, and if at any subsequent time it fails to operate equally well, it is obvious that some deviation from those normal conditions exists, and demands an inquiry into its nature and extent.

For this reason, when starting an engine for the first time, as after erection, it is well to note the positions of the various marks which indicate the shop setting of the valves, the point on the gas cock dial at which the engine starts, etc., and mark them for future reference.

181. Starting the Engine. Everything being in working order, the starting of the engine is a very simple matter, but it should always be preceded by the following operations exactly in the order given.

1. Always keep the engine cleaned of all dirt and dust, and immediately before starting, see that all nuts and bolts are tight, and all split pins in place.

If the engine is of the inclosed crank-case type, fill the crank case with good heavy oil of about 450 to 600 degrees fire test, so that the connecting rod dips into it about three-quarters of an inch. Then thoroughly oil the bearings and cams, the governors and all moving parts, with good lubricating oil; lubricate the valves by puting heavy cylinder oil in the cages through the holes which are usually drilled in the valve stem guides; fill the sight feed lubricators on the cylinder, setting them to feed about six drops per minute; and fill the oil cups on the cam shaft, having adjusted them to feed about two drops per minute.

2. If the engine is provided with a hot tube igniter, turn on the gas to its burner and light it. The flame should be of an

almost invisible blue color, similar to that of a gas stove. If the flame burns yellow, it shows imperfect combustion due to too little air, or that it has lit back. Turn the adjusting screw and give it more air, and if that is not successful, blow it out and relight; get a blue flame and let it burn until the tube has been heated to a dull red heat, before starting.

If an electrical igniter is used, see that the igniter points are bright and clean, and that there is sufficient current to give a good spark. With dry batteries the current should never be less than 6 volts for make-and-break ignition, and should run up to about 10 volts for jump-spark. Test the current by placing a screw driver or other small piece of metal so as to connect the terminal rod and the igniter stem when the igniter points are separated. The spark should be of a reddish color.

If the engine be very cold, remove the igniter cover and warm it so as to prevent the condensation of moisture on the parts from the first explosion, which is very liable to short circuit the igniter.*

For starting, set it as late as possible, as an early spark makes the engine work against itself, and it is therefore harder to start. After starting, the time of ignition can be changed to suit the quality of the gas, or the speed of the engine.

After testing the current, turn it on at the switch.

3. If the engine operates with gasoline, see that there is sufficient gas at the engine by lighting it at the pet cock usually

*The adjustment of the igniter will vary according to the character of the fuel used. For illuminating and gasoline gas, it should break or spark at the moment the crank reaches its inner dead center; for natural gas, it should spark from 5° to 20° earlier (depending on the quality of the gas); and for producer gas about 30° before the crank reaches the same dead center.

located close to the gas valve. It should burn steadily like an ordinary gas jet. If it burns violently, it indicates the presence of air in the gas pipe. This air should be pumped out either by turning the engine over by hand, or by self-starter, with the gas adjustment wide open and the air adjustment closed. If the pressure at the engine is too low, it indicates something wrong with the regulating device. Jar the regulator until it works freely. If the pressure in the main is too low, open the gas adjustment wider than usual.

Set the mixing valve adjustment in the best position for starting, according to the quality of the gas. Adjust the valves so as to give, for illuminating gas, a proportion of 1 to 6 or 10; for natural gas, 1 to 12 or 16; and, for producer gas, about 1 to 1 or 2.

The point of starting depends upon the pressure and quality of the gas.

4. If the engine can be turned over by hand, as is the case with all engines below 25 horse-power, and a great many up to 50 horse-power, turn the gas valve handle slowly, beginning at the 0 on the dial plate; turn the fly wheel backward until it cushions, then forward two or three quick turns, all the way around, and the engine will start.

5. As soon as the engine is started, turn the gas valve handle to the highest mark (10) on the dial. Move the gas and air adjustment to the best running position, and then turn on the cooling water. The cooling water should never be turned on before starting, except in cases where the jacket-water has been previously drained, as a warm engine is much easier to start than a cold one.

If the engine is to be started by compressed air, open the air cocks, at the tanks, so as to fill the pipe leading to the engine

with compressed air. Open the gas valve, and immediately thereafter open the compressed air cock at that cylinder which is temporarily used to run the engine with compressed air. As soon as good explosions occur in the other cylinders, shut off the air cock, throw in the inlet-cam clutch of the starting cylinder, so that it will admit gas for its own explosions. Care should be taken to shut off the air cock before the inlet-cam clutch of the starting cylinder is thrown in, otherwise this cylinder may compress a charge of air to such a high pressure that it will reverse the piston with disastrous consequences.

6. If the ignition current is obtained from a dynamo or magneto, turn the current on from the dynamo, and cut out the battery from the spark coil circuit.

7. Pump up and lock the air tanks at the pressure required to start the engine. The pressure varies according to the type and horse-power of the engine, and ranges from 100 to 250 pounds to the square inch.

182. Failure of Engine to Start. If the engine fails to start, it may be due to one or more of the following causes:

1. The mixture may not contain a proper proportion of gas to air. A mixture either too rich or too lean will fail to ignite. Also, a poor mixture burns so slowly that it might ignite the incoming charge, and cause back-firing. Readjust the mixing valves.

2. The use of a too volatile lubricating oil will produce the same effect. Change the oil.

3. Accumulations of dirt under the admission valve may cause it to leak, thereby allowing the flame to blow-by and cause premature ignition. Clean and re-grind the valve seat with flour emery.

4. A leaky exhaust valve will lower the compression below the point required for ignition, and cause miss-firing. Re-grind the valve, so that it will seat firmly and quietly under the pressure of compression.

5. The igniter points may be dirty, or coated with the moisture of condensation, or they may be too far apart. Clean them with a little gasoline, or with a small piece of No. 0, emery paper, and place them one-sixteenth of an inch apart.

6. Test the ignition current, the battery, the dynamo, the spark coil, and the wiring.

7. The pawls or trips which operate the gas valves may not operate at the right time. Adjust them by tightening or loosening the adjusting screws in the governor collar on the fly wheel.

183. **Management of Engine.** The principal points to which careful attention should be given while the engine is in operation, are as follows:

1. The main bearings should not be allowed to get hotter than the engine frame, or the crank case, while the small bearings which are not heated by the cylinder should be properly lubricated and adjusted to run cool.

2. The jacket-water should not issue from the cylinder at a higher temperature than 150° Fahr., nor colder than 100°, otherwise there will be a great loss of power. The supply of jacket-water must never be interrupted while the engine is running.

3. The igniter cams should be oiled or greased several times a day in order to prevent them from running dry, squeaking and cutting. Likewise, the admission cam shaft, and other small shafts, should receive a few drops of oil or a little grease every three or four hours.

4. Miss-firing must be prevented.

5. All unusual sounds should be carefully observed, their cause located, and the trouble remedied at once. Especial attention should be paid to sounds caused by the improper action of valves.

In short, the engine should run quietly.

6. Effective lubrication should be maintained.

184. Stopping the Engine. To stop the engine, it is necessary to execute the following operations exactly in the order given.

1. Shut off the supply of jacket-water.

2. Shut off the supply of gas.

3. If the igniter current is derived from a battery, switch the latter out of the spark coil circuit. Never leave the battery short circuited, as it will exhaust itself very quickly and require frequent renewals.

4. Throw out starting levers, if there be any, before the engine stops, so as to prevent the engine from turning backwards.

5. Stop the engine in the starting position, otherwise the exhaust valve will be left open, and the outer air will corrode the valve seat and prevent the valve from closing tightly.

Where more than one engine exhausts into the same pipe, close the valve in this pipe as soon as each particular engine stops, otherwise the engines still in operation will drive water into the cylinders of those at rest.

6. Close sight-feed lubricators and oilers, so that they will stop feeding.

7. In freezing weather, drain the water from the water jacket and pipes, and remove the igniter plug.

185. Care of Engine. In order to insure its effective operation, a gas engine should receive intelligent care regularly.

186. Inspection. Inspections should be made often and systematically. In the inclosed crank case types of engine, the hand-hole covers, igniter-plug covers, and valve covers may be readily removed, so as to allow the inspection of the internal working parts.

187. Igniters. The igniters should be removed and examined at least once a week. Those of the make-and-break type require especial and frequent attention. Their points should be kept clean and dry, and their joints tight so as to prevent them from leaking and thus becoming heated. Care should be taken to see that the igniter stems show no signs of sticking, and that the lava or other insulators are not cracked.

188. Valves. The valves should be examined at least once a month, especially the exhaust valve, and if they are discovered to be leaky, their seats should be immediately re-ground, and the valve stems and valve heads properly cleaned. Leaky exhaust valves become burned very quickly, which tends to lower the compression and results in much loss of power.

Water-cooled exhaust valves are liable to become stopped up with scale, so that their stems get heated. They should be removed and the scale punched or drilled out of the small holes below the valve seat.

Admission valves seldom require grinding, but should always be kept clean.

189. Pistons. The pistons should be examined at least twice a year. For proper inspection, a piston should be drawn far enough out of the cylinder to permit of the removal of the piston rings, if necessary, and for the thorough cleaning of the piston ring grooves.

The piston rings should not be allowed to stick tight in the grooves on account of accumulations of rust, dirt, or baked oil. They can be readily cleaned with petroleum, and if any of them are broken, the pieces should be taken out at once and new rings substituted. In putting on new rings, great care should be taken not to bruise, nick, twist, or injure them in any way that will prevent them from expanding freely in the grooves. A twisted or bruised piston ring will not bear evenly against the walls of the cylinder, and will very quickly wear the latter out, causing serious blowing-by or leakage of both the compressed and expanding charges, and consequently a great loss of power. When the erosion of the cylinder has become too excessive to be remedied by the normal expansion of new piston rings, the proper and only thing to be done is to have the cylinder rebored. Care should be taken to see that the rings are not too loose in the grooves, and if such be the case, they should be exchanged for correct-fitting ones at once.

190. **Cleanliness and Carefulness.** It is essential that the engine be kept clean at all times. Whenever the machine is started cold, the subsequent heating tends to loosen all bolts and nuts. It is absolutely necessary that they should be kept tightened at all times. If the bolts and nuts on the cylinder head are allowed to work loose, the force of the explosions is liable to blow the joint out of the cylinder cover. In tightening nuts and bolts great care should be taken not to overstrain them, or they will be very liable to breakage, either during the act of tightening, or subsequently under the expansion of the engine itself.

191. **Lubrication.** Proper lubrication, and the use of a suitable oil for this purpose, are of more importance in the case of a gas engine than in any other piece of mechanism.

As to the quality of oil, any kind or plain engine oil cannot be used. No vegetable or animal oil should be used for this purpose. In fact, nothing but a mineral oil of high flash point can be used at all. Gas engine oil must possess what is commonly called *"body,"* or the capacity to retain sufficient viscosity, under the thinning influence of heat, in order to lubricate effectively. Oil susceptible of being readily burned will not only deposit carbon and gum on the cylinder walls, piston heads, and spark plugs, but will also form injurious deposits in the piston ring grooves and between the rings, thereby greatly interfering with their free expansion, and causing leakage and faulty compression.

Even when using the most suitable kind of oil, gas engine lubrication has to be very carefully arranged, especially in the case of high speed engines.

In all cases, the principal condition which must be satisfied is the delivery of the proper quantity of oil to the different working parts of the engine. The feeding of too small a quantity of oil will result in great damage to the cylinder by scoring, and to the bearings by cutting and excessive wear. On the other hand, the delivery of too much oil will result in fouled igniter plugs, causing short circuiting; smoky exhaust; carbon deposits on the piston heads and cylinder walls in sufficient quantity to cause pre-ignition, and decrease of the clearance space causing over-compression and consequent pounding of the engine.

The usual lubricating arrangements consist of various forms of sight feed lubricators and oil cups for the cylinders, pistons, wrist pins, cam shafts, etc., which can be set to feed the exact quantity of oil required for the proper lubrication of those parts under varying speed. The main bearings are usually

equipped with ring oilers as shown in *Fig.* 53. The rings, A and B, move freely with the main shaft and dip into the oil reservoirs, C and D, which are filled through the funnel-shaped holes, E and F, in the bearing caps, G and H.

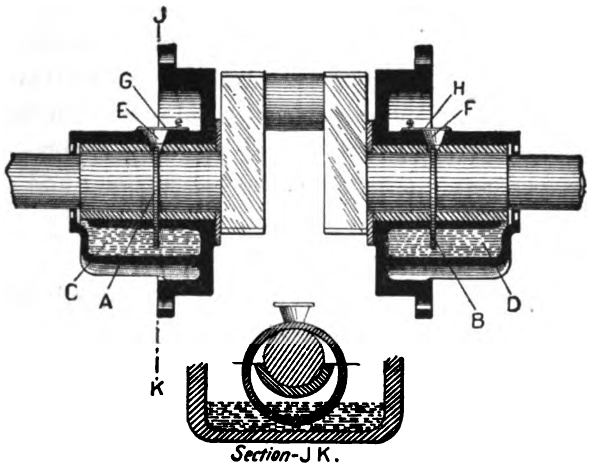

FIG. 53.—RING OILER.
(Paragraph 191.)

CHAPTER XV.

FOUR-CYCLE HORIZONTAL ENGINES.

192. **Horizontal, Single-Acting Engines.** The machines described in this chapter represent some of the standard types of modern gas engines. The majority of them are readily convertible into gasoline and oil engines by the use of the necessary carburetters or vaporizers, but oil engines, proper, or those especially designed for using liquid fuel in the form of kerosene, crude petroleum, distillates, etc., are described in Chapter XX.

The engines herein described have not been selected for that purpose because they were considered the best of their kind on the market. A great many other makes represent quite as fine workmanship, and possess equally as good power-producing capacities. The present selection is made rather with a view to the description of certain standard forms which appear to cover all the peculiarities of construction of the best types of modern gas and gasoline engines belonging to the four-cycle, single cylinder, horizontal, single-acting type.

193. **The Otto.** The construction of the Otto engine was begun in 1867. It was the first practically successful engine of the four-cycle compression type. At the present time it is built in sizes ranging from the smaller powers to 200 horsepower. The frame is of substantial pattern with well-rounded corners and a broad bearing on the foundations. The cylinder overhangs the frame, and in the larger sizes is supported by a heavy cylinder-foot immediately in front of the valve gear. The

engine is equipped with a long connecting rod which serves to lessen the vertical thrust upon the piston, thus adding to the tightness and durability of both piston and cylinder by diminishing friction and consequent wear.

Fig. 54, gives a general view of a 50 horse-power engine; *Fig.* 55, an enlarged view of the side of the cylinder; and *Fig.* 56, a similar view of the end of the cylinder.

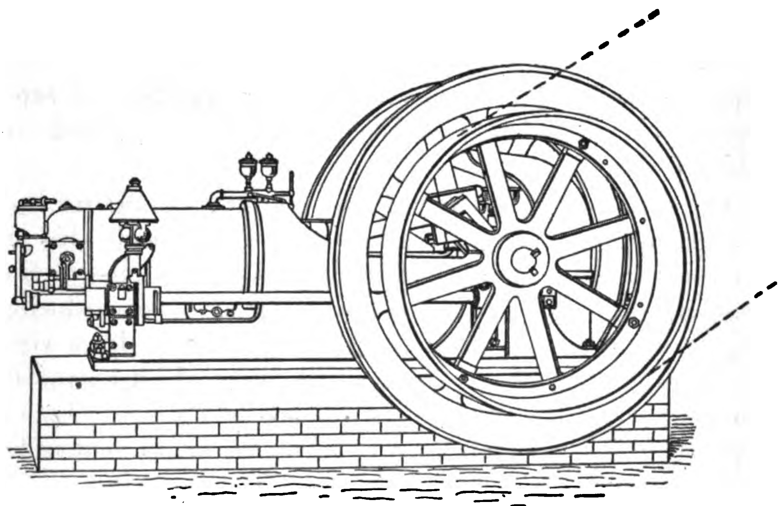

Fig. 54.—50 Horse-Power Otto Engine.
(Paragraph 198)

The arrangement of the parts varies somewhat in the different designs, but the general action is practically the same in all sizes.

Referring to *Fig.* 55, when gasoline is used, it is delivered by the gasoline pump driven by an eccentric on the side shaft, into the standpipe from which it gravitates to the gasoline valve, A, which regulates the quantity of gasoline and the time

of its admission, so as to supply automatically the proper mixture of air and gas according to the requirements of the varying load. The valve, A, is operated by the cam, B, on the side shaft, C, the cam actuating a rocker shaft, D, the lower arm of which is fitted with a long pin which carries the gasoline roller, E. This roller has a free lateral movement which is governed

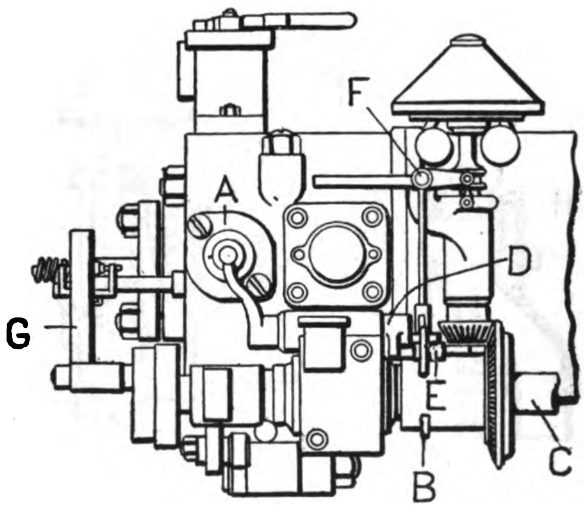

Fig. 55.—Otto Engine Cylinder.
Enlarged View of Valve Gear Side.
(Paragraph 198)

by the vertical arm of the bell crank, F, connected with the governor, a very slight movement of which is sufficient to place the roller in or out of engagement with the cam on the shaft. The speed of the engine is regulated by the governor which changes the position of the gasoline roller, so that the fuel is admitted only when the speed is normal or slightly below it. The governor is of the fly-ball weighted type.

Ignition is effected by an electric spark, the igniter being operated by the igniter lever, G, actuated by the side shaft. The electrodes of the igniter are tipped with platinum, and the current is derived from a primary battery.

As shown in *Fig.* 56, the exhaust valve, H, is operated by the exhaust lever, J, fulcrumed beneath the cylinder, and actuated by a cam on the side shaft. The cylinder, cylinder head, and

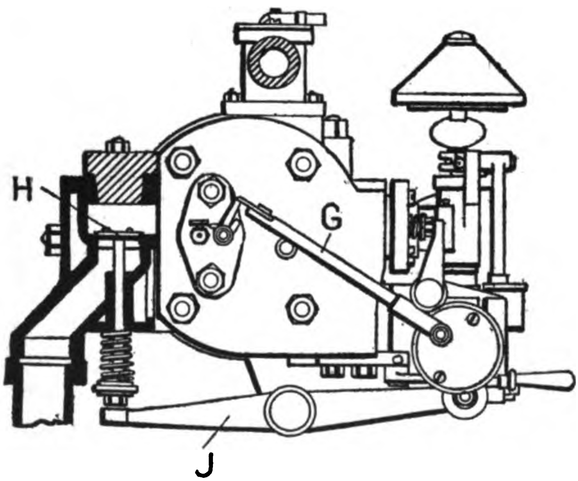

Fig. 56.—Otto Engine Cylinder.
Enlarged View of Cylinder End.
(Paragraph 193)

exhaust valve box are amply water-jacketed. The piston and the crosshead pin are lubricated by means of special oil cups placed on the cylinder near the front end. The crank pin is oiled by means of a wiper fed by a sight feed cup, and the main bearings by ring oilers which dip into an oil reservoir beneath the bearing.

The Otto engines are usually made with single cylinders placed horizontally. Several designs of the smaller sizes, from

1 to 3 horse-power, are made with vertical cylinders. They are suitable for small pumping stations, newspaper plants employing a cylinder press and three or four platens, ice cream manufacturers, and other industrial plants which require small, economical power producers. Otto vertical cylinder pumping engines are made in sizes from 3 to 150 horse-power, while

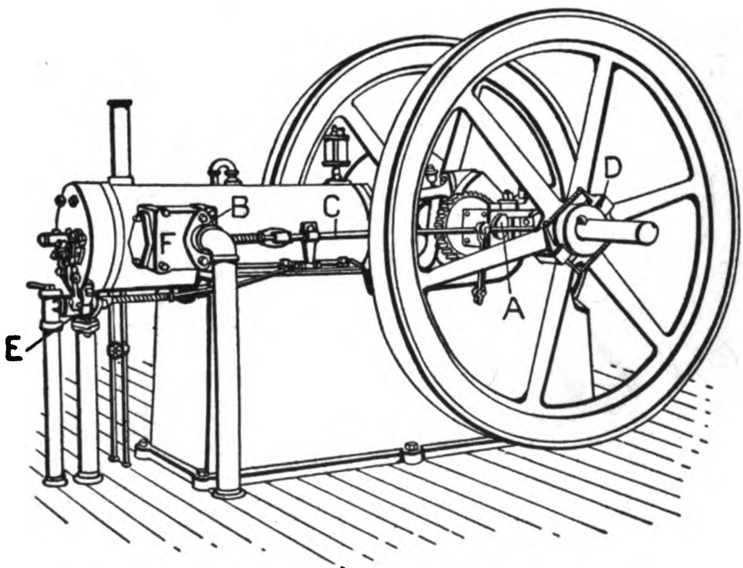

Fig. 57.—Fairbanks-Morse Horizontal Engine.
(Paragraph 194)

those of the regular horizontal type range from 4 to 200 horse-power.

194. **The Fairbanks-Morse.** These engines are of the four-cycle single acting type, but they are made in all sizes with either horizontal or vertical cylinders, the former usually of the single cylinder, and the latter of the multi-cylinder, type.

Fig. 57, gives a general view of a 60 horse-power horizontal engine, and *Fig.* 58, a view of the patent self-starter arrangement.

As shown by *Fig.* 57, the engine has two poppet valves both of which are protected by water jackets. A single cam, A, operates the exhaust valve, B, through a straight rod, C, carried

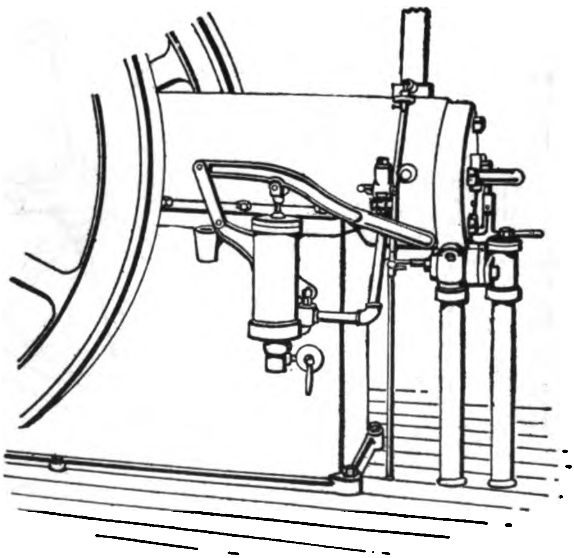

Fig. 58.—Fairbanks-Morse Self-starter.
(Paragraph 194)

in suitable guides, and represents practically all of the valve gear of the engine. The governor, D, is attached to the fly-wheel and acts directly upon the exhaust valve. This device relieves the engine from compression, and at the same time cuts off the supply of gas when not required. *Fig.* 57, also shows the position of the admission valve, E, and the arrangement of

the cylinder head. The exhaust chest, F, is attached to the cylinder by studs, and is therefore, capable of being removed at small cost whenever necessary. The connecting rod is adjustable at both ends, at the piston end by means of a screw and wedge, and at the crank end by means of bearing boxes of the marine type. Ignition is effected by an electric spark, but tube igniters are also provided.

The horizontal engines are equipped with the self-starter arrangement shown in *Fig.* 58. In starting, the detonator is charged and inserted in the fixture attached to the cylinder; the pump is then operated and a charge forced into the cylinder and ignited by the detonator or by a spark from an electric igniter. The resulting expansion has sufficient force to start the engine under about half load, without shock, a most essential feature in the management of a gas engine. With this arrangement, one man can start an engine of from 5 to 100 horsepower. The method in vogue with the vertical types differs from that of the horizontal in that the charging pump is not used on sizes below 12 horse-power. In those the starting is accomplished by means of a crank placed on the end of the crank shaft; this crank has a pawl which is engaged in a slot in the crank shaft, so that, when the handle is revolved in the regular direction of motion of the engine, sufficient speed is obtained, from a few turns, to effect an ignition which will run the engine away from the pawl of the starting crank, thus permitting its removal.

Engines of the same design, suitable for burning kerosene and the heavier grades of crude oil, are described in Chapter XX.

195. **The Foos.** All of the Foos engines are of the four-cycle, single cylinder, horizontal, single-acting type. Nearly

all the working parts are assembled on one side of the cylinder, thereby facilitating installation, and giving free access to the devices for regulating the speed, the fuel and air supply, the time of ignition, and for starting the engine.

Fig. 59, shows the valve gear side of the engine, and *Fig.* 60, a cross section through the cylinder and valve chambers.

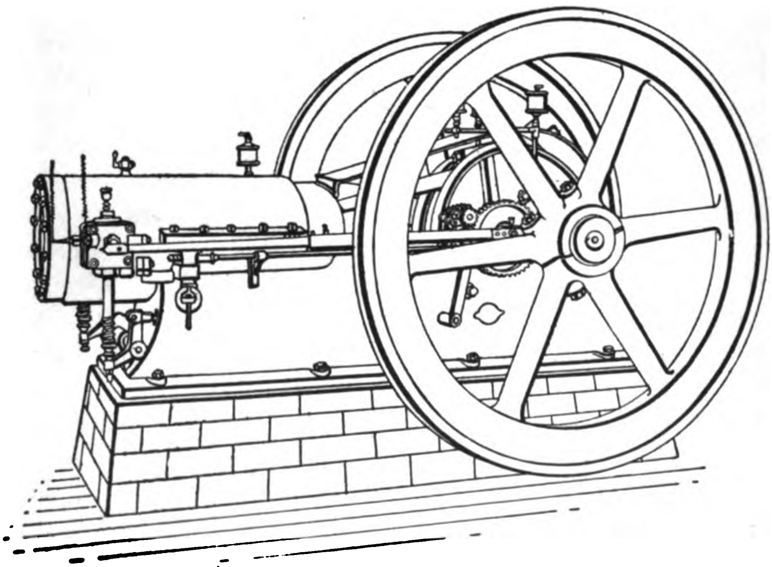

Fig. 59.—Foos Gas and Gasoline Engine.
Valve Gear Side.
(Paragraph 195)

The design is the same for all sizes, the cylinders being bolted to the beds by long ways which project from the sides. The water jacket is large and cast solid with the cylinder. It is closed at the end of the cylinder head, which is itself thoroughly water-jacketed, and is capable of removal so as to permit the clearing away of obstructions sufficiently large to interfere with the circulation.

Referring to *Fig.* 60, it will be noted, that the admission valve, A, and the exhaust valve, B, are placed in separate water-jacketed castings on opposite sides of the cylinder, and communicate by means of large ports with the combustion chamber, C. These valves are of the vertical poppet type, and are positive in their action. As the weight of the valve acts in the

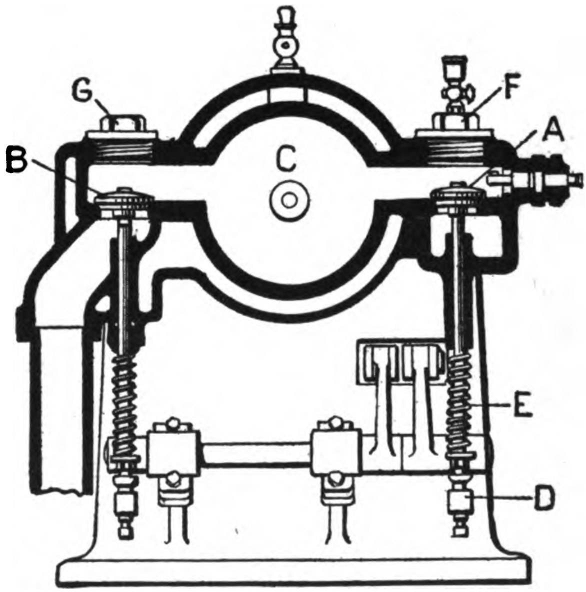

Fig. 60.—Foos Gas and Gasoline Engine.
Cross section through Cylinder and Valve Chambers.
(Paragraph 195)

direction of its motion it returns naturally to its seat and maintains a tight contact even without the aid of a spring.

Suction in the cylinder is not relied upon to open the admission valve; it being lifted positively by the lever, D, and closed by its own weight aided by the action of the strong spring, E. Although the valves are in separate removable boxes it is not

necessary to detach these boxes in order to remove the valves. The admission valve can be taken out by unscrewing the plug, F, and the exhaust valve by removal of the plug, G. The valves can be ground in when necessary by the use of an ordinary brace and bit.

The valve gear is operated through steel cams driven by machine cut gears; and by adjusting, with a common wrench, the screws carried by the lift lever, D, any wear or looseness in the valves may be quickly and effectively taken up.

The governor is of the centrifugal type. It is of simple and compact construction and regulates the supply of fuel by cutting out the charges beyond those required to maintain uniform speed.

The igniter is of the electric wipe-contact type, and is located in the admission chamber directly over the admission valve.

The engines are made in sizes from 2 to 80 horse-power, and self-starters are furnished with several different types ranging above 26 horse-power.

196. The Wayne. These engines are all of the four-cycle, single cylinder, horizontal, single-acting type, and are designed for using either gas or gasoline.

Fig. 61 shows a general view of the valve gear side of the engine; *Fig.* 62, a sectional plan through the cylinder and valve chambers; and *Fig.* 63, the valve gear mechanism and governor.

The cylinder is bolted to the engine frame, and is provided with a water jacket of ample proportions having large openings for the removal of lime, sand, or other deposits.

The cylinder head forms part of the combustion chamber and contains all the valves and the devices for starting and igniting.

The valves are of the poppet type and are operated by a rod and lever actuated by a single spring and cam.

The governor is of the centrifugal fly-ball type. It is geared to the cam shaft and controls the engine by cutting off or admitting the fuel supply according to the requirements of the load.

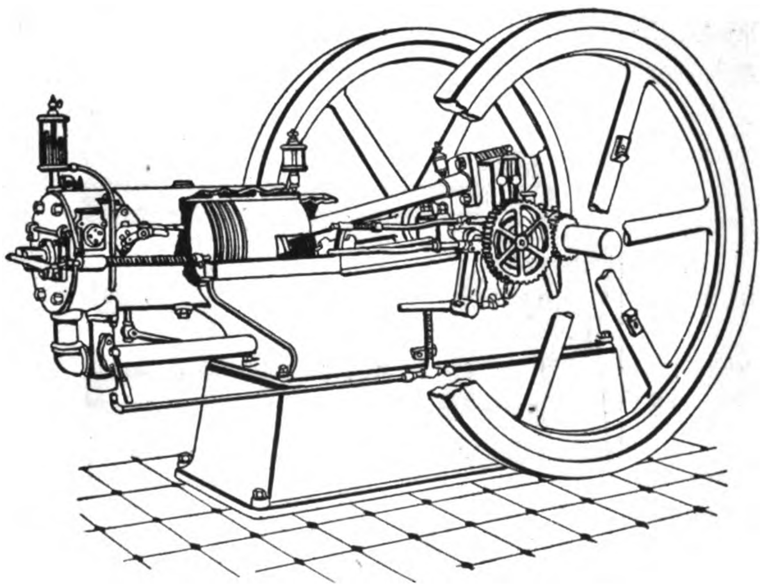

Fig. 61.—Wayne Gas and Gasoline Engine.
Valve Gear Side.
(Paragraph 196)

Referring to *Figs.* 62 and 63, this action may be described as follows: The valve rod, A, is operated by the cam, B, on a short secondary shaft, C, geared to the main shaft, D. When the action of this cam throws the rocker arm, E, to the left, it opens the exhaust valve, F; and when the valve rod is released by the cam, the spring, G, returns the rod and opens the gas

valve, H, delivering the fuel to the admission valve, I, which is opened directly into the chamber by atmospheric pressure. During a normal charging stroke, the valve rod is entirely released by the cam and holds the gas valve open by means of the spring, G, to the end of the stroke. The rod then releases the gas valve and takes an intermediate position during the compression and working strokes. At the end of the working stroke, the cam comes again into position and pushes the valve rod clear out, thus opening the exhaust valve.

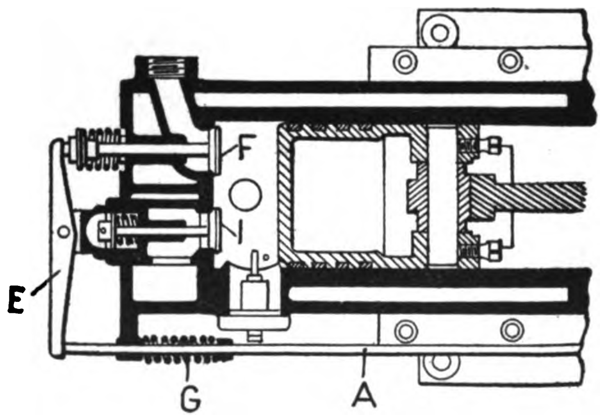

Fig. 62.—Wayne Engine.
Sectional plan through Cylinder and Valve Chambers.
(Paragraph 196)

This is the cycle that conforms to normal speed; but, when the speed increases excessively, the governor lifts the end of a latch, J, which engages a lug on the rocker arm, K, thus holding the valve rod back and allowing the gas valve to remain closed so that air only enters into the cylinder through the admission valve.

Ignition is effected by electric spark, through a hammer-break igniter operated by a separate firing rod, L, which is actuated

by an individual cam, so that the blade, M, on the end of the firing rod engages an arm, N, on the spindle of the igniter. The release of the arm is affected by the movement of a triangular block, O, on the end of the firing rod, which rides up on the roller, P, and throws the end of the pick-blade above the end of the igniter arm.

These engines are built in sizes from 6 to 150 horse-power.

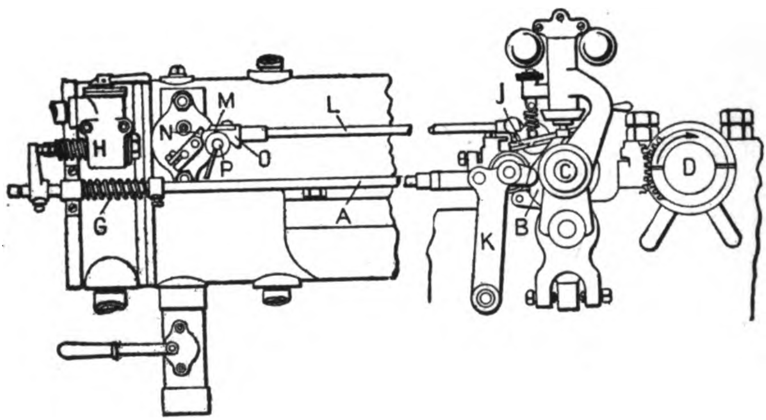

Fig. 63.—Wayne Engine, Valve Gear and Governor. (Paragraph 196)

197. **The Model.** All of the Model gas and gasoline engines are of the four-cycle, single-cylinder, horizontal, single-acting type. One feature particularly noticeable in their design is the absence of a separate cylinder head; the cylinder and water jacket consisting of a single casting, in which the only openings in the water jacket are those for the water pipe connections.

The valves are of the poppet type with long stems which permit of their being raised squarely from their seats. They are placed in a small box entirely separate from the cylinder, and

are therefore capable of being renewed with the least possible expense.

Fig. 64, shows the valve gear side of the engine. For complete description of engine parts, see *Figs.* 51 and 52.

The governor is of the centrifugal type, and regulates the speed of the engine by cutting out the charges beyond those required to maintain uniform speed. It is of very simple construction. At normal speed, a dog holds the governor cam and prevents its action, but when the speed increases, the raising of the point of the dog releases the cam and allows the governor to act. As the amount of displacement necessary to release the cam is from $\frac{1}{16}$ to $\frac{1}{8}$ of an inch, the governor is very sensitive, but in order to make it as much so as possible, and also to take up the wear, both cam and dog are provided with set screws and lock nuts for raising or lowering the point of contact. The speed of the engine can be increased or decreased by means of a screw which acts on the tension spring of the governor.

Ignition is effected by an electric spark obtained by means of a make-and-break igniter of very simple but effective construction, operated by an individual rod actuated by the main shaft through the valve gear mechanism. It is capable of being readily removed and replaced, whenever necessary, in a few moments, without interfering with any other part of the engine, and the time of ignition can be changed while the engine is in operation, without removing any part thereof, by means of a screw which lengthens or shortens the igniter rod.

These engines are built in sizes from 2 to 75 horse-power. The design is the same for all sizes, and the engines can be adapted for using kerosene and crude oils by the mere addition of a fuel tank, as the engine takes the oil directly into the cylinder, and, therefore, does not require a vaporizer. When

kerosene or crude oil is used the engine is operated for the first five minutes on gasoline, then the gasoline supply pipe is closed, and the oil turned on; no heating of the engine previous to starting being required.

198. **The Olds.** These engines are built in two classes known to the trade as Type A and Type G. Both types are

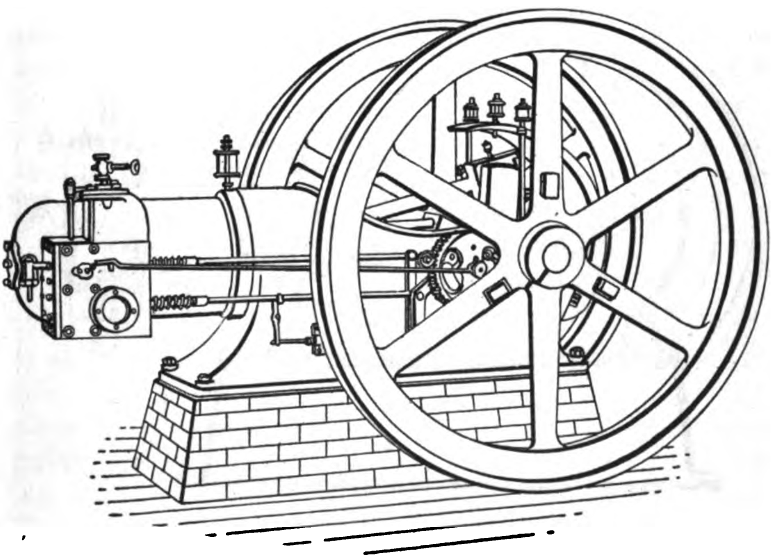

Fig. 64.—Model Gas and Gasoline Engine.
Valve Gear Side.
(Paragraph 197)

four-cycle, single cylinder, horizontal, and single-acting, but differ from each other in details of construction. As type A is the later product, and undoubtedly represents the best effort of the makers, its description will be sufficient in this connection.

Fig. 65, represents a sectional view of Type A; *Fig.* 66, the carburetter; and *Fig.* 67, the governor.

In the arrangement provided for the proper proportioning of the charge, the fuel comes to the mixer under a slight gravity head of about 3 inches, and, at each working stroke, a small amount is admitted by the opening of a needle valve, A, in the carburetter, *Fig.* 66, the lift of the valve being allowed to reg-

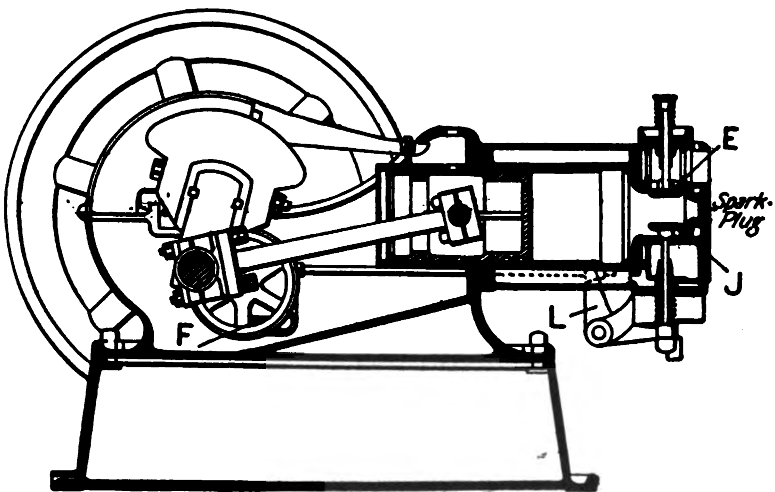

Fig. 65.—Olds Engine.
Longitudinal Section, Type A.
(Paragraph 198)

ulate itself, while the flow of gasoline is controlled by the screw needle valve, B, in the supply pipe. Air is admitted through an annular opening, C, around the gasoline jet, the blast serving to spray the fuel and thus form the explosive mixture. At very low speed, the force of the blast through the normal opening is not sufficient to spray the fuel satisfactorily. This is remedied by the provision of a movable washer, D, which is

pushed up against the air admission opening at starting, thus cutting down the area of that opening and increasing the velocity of the air passing through it. From the mixer, the charge is drawn into the cylinder through a spring-closed admission valve, E, *Fig.* 65, and there ignited by a jump-spark. The spark points of the igniter are placed in the center of the cylinder head and directly in the path of the incoming charge, so that not only are the points swept clean at every working

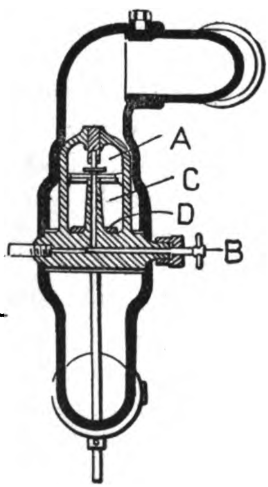

Fig. 66.—Olds Engine.
Carburetter.

(Paragraph 198)

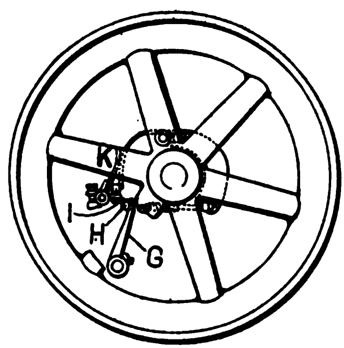

Fig. 67.—Olds Engine.
Governor.

stroke, but they tend to inflame the charge uniformly in all directions. The electric current is derived from a dynamo, and the make-and-break mechanism of the igniter is mounted outside of the engine frame, on the lever which operates the exhaust valve. A depression on the operating cam drops the lever and brings the electrodes in contact, and the rise which immediately follows breaks the circuit.

The governor is of the centrifugal fly-ball type as shown in *Fig.* 67, and controls the speed of the engine by the hit-or-miss method. A rocker arm, F, *Fig.* 65, is placed below the main shaft and driven by a cam on a geared secondary shaft which makes one revolution for every two revolutions of the main shaft. The rocker shaft carries an arm, G, *Fig.* 67, on the end of which is a catch, H, which is engaged by a pawl, I, so that the exhaust valve, J, *Fig.* 65, is held open and causes the engine to miss an explosion whenever necessary. The pawl carries, at right angles to itself, the curved arm, K, *Fig.* 67, which is engaged, by a similar arm on the governor weight, while the engine is at or below normal speed; but, when the speed increases and the governor rises above the normal position, it fails to hold out the pawl, so that it engages the arm on the rocker shaft and prevents the operation of the valve. From the rocker shaft near the main shaft, a link rod drives a rocker arm, L, *Fig.* 65, located under the head of the cylinder. This rocker arm lifts the exhaust valve by means of a swinging bail. The rod which keeps the admission valve closed, during the period of an omitted explosion, passes up through the valve chest and acts on the valve by holding under the spring on the valve stem. The igniter electrodes are mounted one on the rocker shaft and the other on the engine frame.

All working parts are placed in the cylinder head and mixing chamber, thus making the cylinder as simple as possible, a mere interior barrel with flanges, surrounded by an outside barrel, the annulus between which forms the water jacket. The water jacket is packed at each end between the two barrels, and provided with an outlet for the water, the inlet for the water being in the cylinder head, which is a single casting making a ground joint with the cylinder. The cylinder head is divided into two compartments, one for ignition, provided with openings for the

admission and exhaust valves, and one for cooling water which passes into the jacket through annular openings near the circumference. The mixer consists of a separate casting bolted to one side of the cylinder head and containing the reservoir for gasoline, the regulating needle valve, and the operating needle valve.

In order to maintain a constant compression, the main bearing is made with the side farthest from the cylinder as a separate block having a double wedge on its back. Two wedge blocks drawn together by means of a bolt, operate to press the shaft constantly towards the cylinder, and thus take up the wear of the bearings on the side on which it occurs. A compression of 75 pounds gives the best result for a gasoline mixture.

These engines are made in sizes from 2 to 125 horse-power.

199. **The Weber.** These engines are of the four-cycle, single cylinder, horizontal, single-acting type. They are designed for using either gas or gasoline, and are proportioned throughout to withstand the severest service successfully.

Fig. 68, shows a side view of the engine, and *Fig.* 69, a partly sectional view of the mixer.

The valve gear is of simple design, all of its component parts being placed at the side of the cylinder near the cylinder head. The valves are of the poppet type, the exhaust valve being actuated by means of a rocker arm operated by a cam on the side shaft. The gasoline pump is bolted to the side of the engine frame, beneath the shaft, and is operated by a cam on the side shaft, the fuel being injected into the cylinder in the proper quantity and only as frequently as is required to maintain uniform speed.

The governor is of the centrifugal fly-ball type. It actuates a bell crank lever, the lower or longer arm of which is provided with a steel block which engages a corresponding block on the lever operated by the cam on the shaft, and which in turn actuates the plunger of the pump. When the speed increases

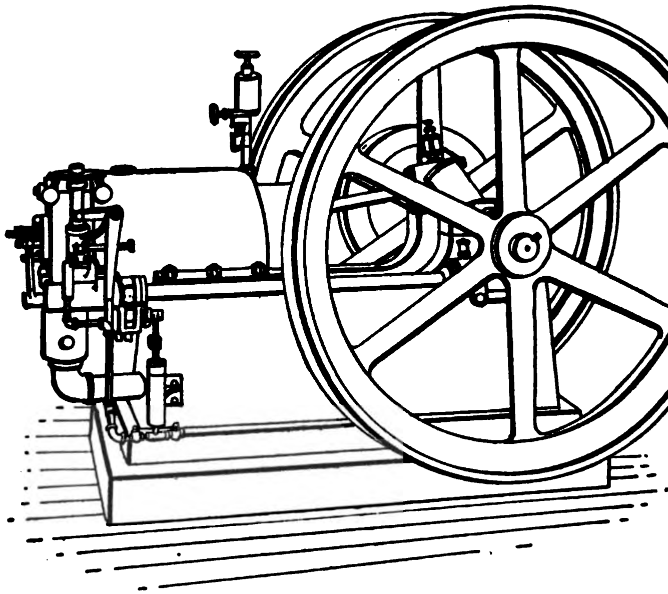

FIG. 68.—GAS AND GASOLINE ENGINE.
Valve Gear Side.
(Paragraph 199)

above the normal, the long arm is caused to swing slightly towards the right, engaging the lever which operates the pump plunger, and preventing the latter from rising, thus stopping the action of the pump. As the difference in the lengths of the arms of the bell crank is comparatively large, a slight movement of the governor is sufficient to bring the steel blocks either into or out of engagement, and thus permit a very close regulation.

When the fuel is gasoline, it is used in its natural state, without the intervention of any gasifying devices between the fuel supply and the cylinder. The gasoline is usually stored in a tank placed outside of the building occupied by the machinery, and direct connections are made with the engine by means of ¼ or ⅜ inch piping.

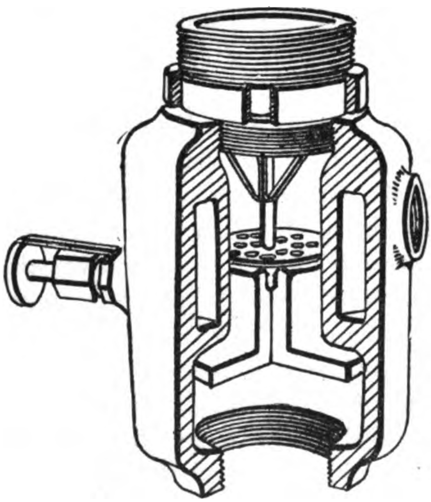

FIG. 69.—WEBER ENGINE CARBURETTER.
(Paragraph 199)

The mixer shown in *Fig.* 69, consists of a heavy iron casting which confines the injected gasoline within strong walls immediately after it leaves the pump, and thus prevents the occurrence of an explosion outside the cylinder.

The cylinder and valve chambers are provided with ample water jackets. Proper lubrication of all the important bearings is effected by sight feed oil cups, and a special oil cup is provided for the lubrication of the cylinder.

Ignition is effected either by hot tube or by electric igniter.

200. The White-Blakeslee. All of these engines are of the four-cycle, single cylinder, horizontal, single-acting type. They are built in massive proportions, and are well calculated to sustain sudden strains and stresses.

Fig. 70, gives a general view of the engine and shows the positions of the governor, valve gear mechanism, and igniter arrangement.

The speed of the engine is regulated by varying the volume of the charge by the action of a throttling governor operated from the side shaft by means of bevel gears.

The mixer, A, consists of a casting of irregular shape located directly under the cylinder, and connected with air supply pipe, B, leading from the sub-base, and the gasoline supply pipe, C, leading from the pump, D. Both of these connections are controlled by valves which require, under normal conditions of operation, merely to be opened to the proper positions as stated in the directions. In extremely cold weather, however, the air valve may be changed so as to thoroughly vaporize the gasoline mechanically, and without the application of heat. The butterfly valve, E, operated by the governor, is located at the upper end of the mixer with the admission valve, F, immediately above it and below the cylinder. By this arrangement, the charge is formed at the instant before it is required by the engine.

The governor is of the centrifugal fly-ball type and operates without the aid of springs.

The igniter mechanism is arranged so as to bring the electrodes into contact for a very short period of time, thus giving an effective spark from a very small amount of current.

201. The Burger. Although these gas and gasoline engines are of the regular four-cycle, single cylinder, horizontal single-

acting type, they possess a characteristic automatic action due to a governor which is a modification of the Rites inertia governor.

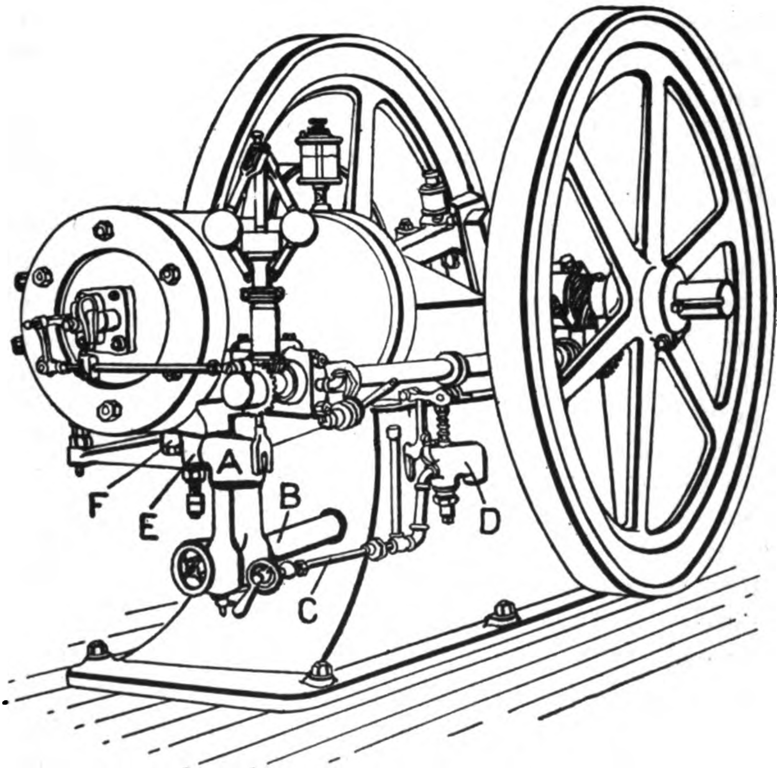

Fig. 70.—White-Blakeslee Engine.
(Paragraph 200)

Fig. 71, shows the valve gear side of the engine, and *Fig.* 72, a horizontal section through the cylinder and valve chambers.

Referring to *Fig.* 71, the governing mechanism and its action may be briefly described as follows: A pinion, A, rotatable on the end of the main shaft, carries a wrist pin which is connected to an eccentric rod, B. The sector of the governor, C, meshes with this pinion and by rotation changes the position of the wrist pin with reference to the crank. *Fig.* 72, shows that the governor valve, D, is cylindrical and provided with ports which register with corresponding ports in the valve casing. These ports are formed in sets, each one containing four ports. The two sets to the right are air ports, and the two to the left are gas ports. The admission valve, E, projects into the cylinder and carries the gas valve, F, on the outer end of its stem.

The suction stroke opens the admission valve and with it the gas valve, and allows the gas to pass from the outer chamber, G, to the inner chamber, H, and thence through the gas ports in the governor valve into the cylinder; the respective amounts of air and gas admitted through the ports being determined by the length of time during which the ports remain open. If the engine is running on quarter-load, the ports will remain wide open during one-fourth of the piston stroke, and if on half-load, during one-half the stroke. The stroke of the valve, however, is always the same; therefore, in order to obtain the automatic effect, it is necessary to rotate the pinion so as to change the position of the wrist pin relative to the crank.

The exhaust valve, I, is of the poppet type and held firmly against its seat by the helical spring, J. The two to one gear which operates this valve through the side shaft, is mounted on the main shaft between the engine bed and the cheek of the crank, the larger gear carrying the exhaust and igniter cams.

Ignition is effected by means of an electric spark from a movable igniter plug, K, *Fig.* 71, fitted into a hole communicat-

ing with the upper part of the cylinder, the current being derived from a battery or from a dynamo attachment driven by the engine itself.

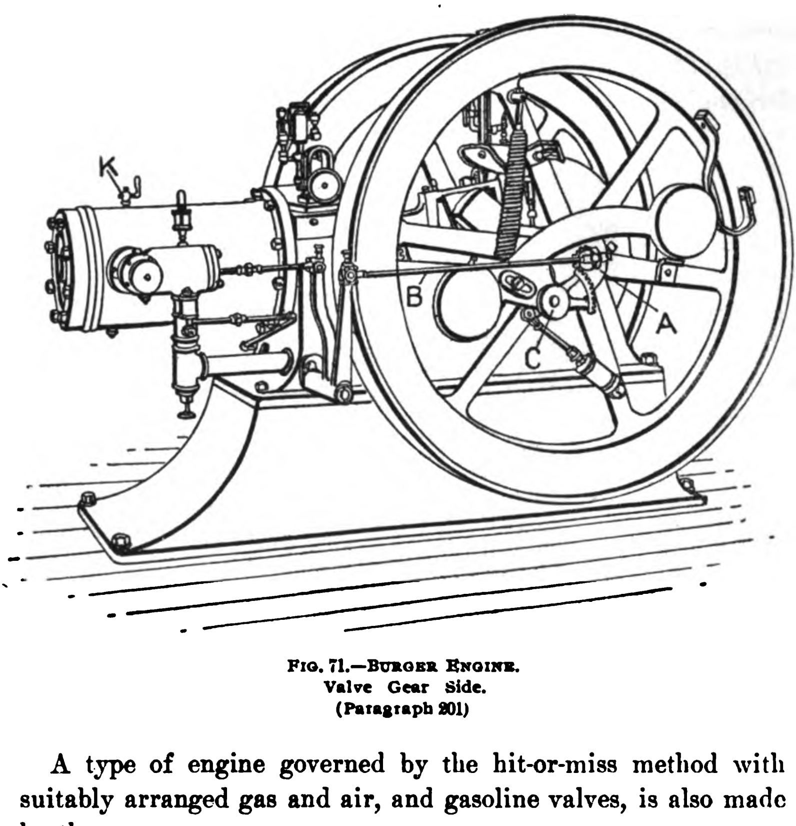

FIG. 71.—BURGER ENGINE.
Valve Gear Side.
(Paragraph 201)

A type of engine governed by the hit-or-miss method with suitably arranged gas and air, and gasoline valves, is also made by the same company.

202. The American Crossley. This engine is similar in all particulars of design, material, and workmanship, to the English Crossley engine, but is manufactured in the United States.

It is of the four-cycle, horizontal, single-acting type, but it is built in single cylinder, double cylinder, and four cylinder units of from 50 to 1,400 rated horse-power. Its details incorporate an experience of over thirty years, Messrs. Crossley having constructed the first commercially successful gas engine in 1876.

Fig. 73, shows a side elevation of the *vis-a-vis* double cylinder engine, and *Fig.* 74, a longitudinal section through the

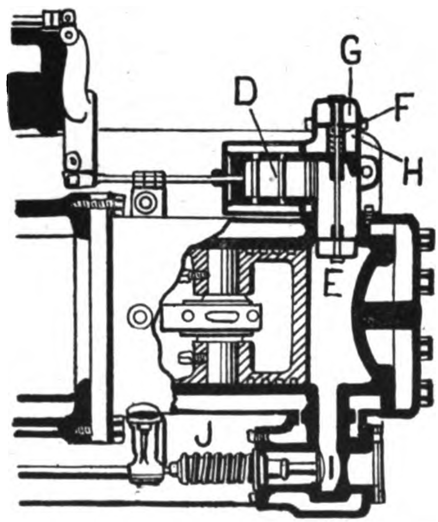

FIG. 72.—BURGER ENGINE.
Sectional View of Valve Chambers.
(Paragraph 201)

cylinders. The crank shaft has a center crank, A, and the two connecting rods, B and C, work on one crank pin, D, the rod, C, having a single box end and the rod, B, a forked end, the two boxes of which work on either side of the box of C, The main bearings are carried in the side frames, E, the ends of which are bolted to the cylinders. A steel crank pit, F, is

located between the side frames and serves to receive the waste oil, while the top is surmounted by a sheet-steel oil guard, G. The crosshead pins, H, are pressed in the connecting rods and work in adjustable bearings in the pistons. The pistons are water-cooled and are also provided with slippers, K, an important feature rarely found in single-acting engines. The main cylinder casting, L, which comprises the water jacket, is provided with extensions and flanges, M, on both sides, by which it is bolted to the side frames. The bottom of the cylinder has a foot, N, which is held down by foundation bolts. The working cylinder proper consists of a liner, O, circumferentially ribbed on the end exposed to the high initial temperatures and pressures, thus providing great strength and ample cooling surface. The cylinder head, P, is hollow and contains the admission and exhaust valves, the latter being inclosed in an independent water-cooled casting, Q, bolted to the bottom of the cylinder.

The valve gear is driven from the main shaft by means of spiral gears and the side shaft, R, the governor being driven in a similar manner by the side shaft, S.

Under this arrangement, the operation of the valve gear and governor mechanism at each end of the engine is as follows: The air and gas enter the mixing chamber, T, through the proportioning valve, the air entering the mixing chamber direct and the gas entering through a gas valve located at, V. From the mixing chamber, the air and gas pass to a cut-off valve and an admission valve located at W. The admission valve is opened by a cam on the secondary shaft, R, through a modified bell crank, X. The cut-off valve is of the multi-ported type and is operated independently of the admission valve by means of a rocker arm which also receives its motion from the secondary shaft, R.

When the load is constant, the cut-off takes place at the same point in each suction stroke, but when the load varies, the altered speed of the governor will move the rod, 1, by means of the rack, 2, so that a pinion will turn a screw which will move the rod attached to the rocker arm in and out, thus changing the position of the fulcrum of the latter and altering the point of cut-off.

This method of governing controls the speed of the engine throughout the ordinary range of loads, but when the load becomes light enough to make this throttling method uneconomical, the engine automatically changes over to the hit-or-miss method.

All of the engines described in this chapter are built in satisfactory types for application to most purposes for which power is required. Owing to the greatly superior fuel economy of the small gas engine over the small steam engine, the former is ideal for purposes of public utilities in connection with small urban or semi-rural localities, more especially those where coal is dear. For most of the applications of small stationary prime movers, gas engines may be satisfactorily installed.

They may be combined with gear-driven multiple well pumps for supplying small waterworks; with exhausters or pumps for drawing natural gas from deep-lying strata after the initial rock pressure has disappeared; or they may be directly coupled to centrifugal pumps in connection with irrigation or reclamation schemes, or for emptying graving docks.

Gas engines are used in large numbers to drive dynamos for electric light or power, either directly connected, or through a belt or rope drive. In the former case, it is necessary to employ multi-cylinder units to promote the necessary steady turning impulse and reduce the "winking" of the light occasioned

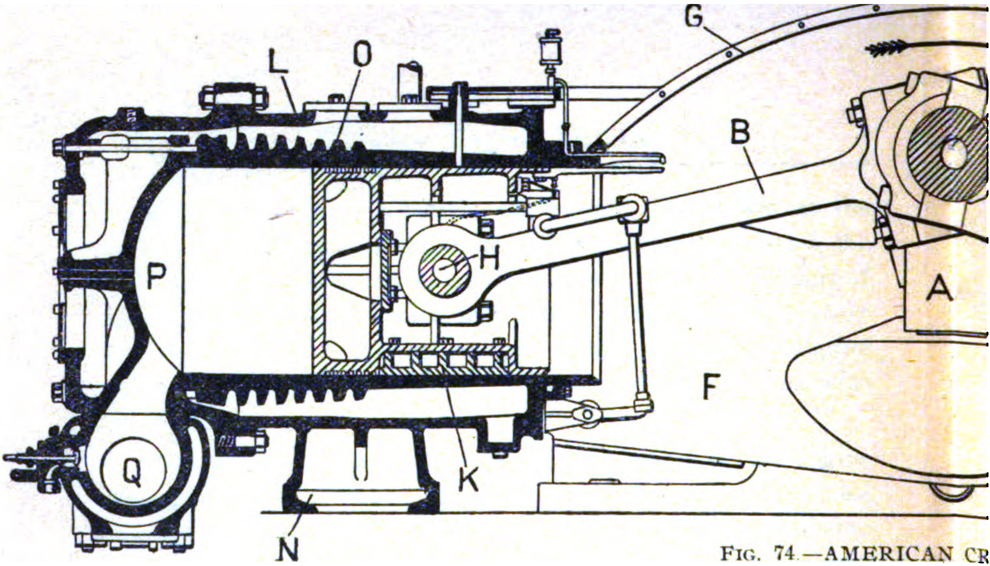

FIG. 74.—AMERICAN CR

Longitudinal Section th

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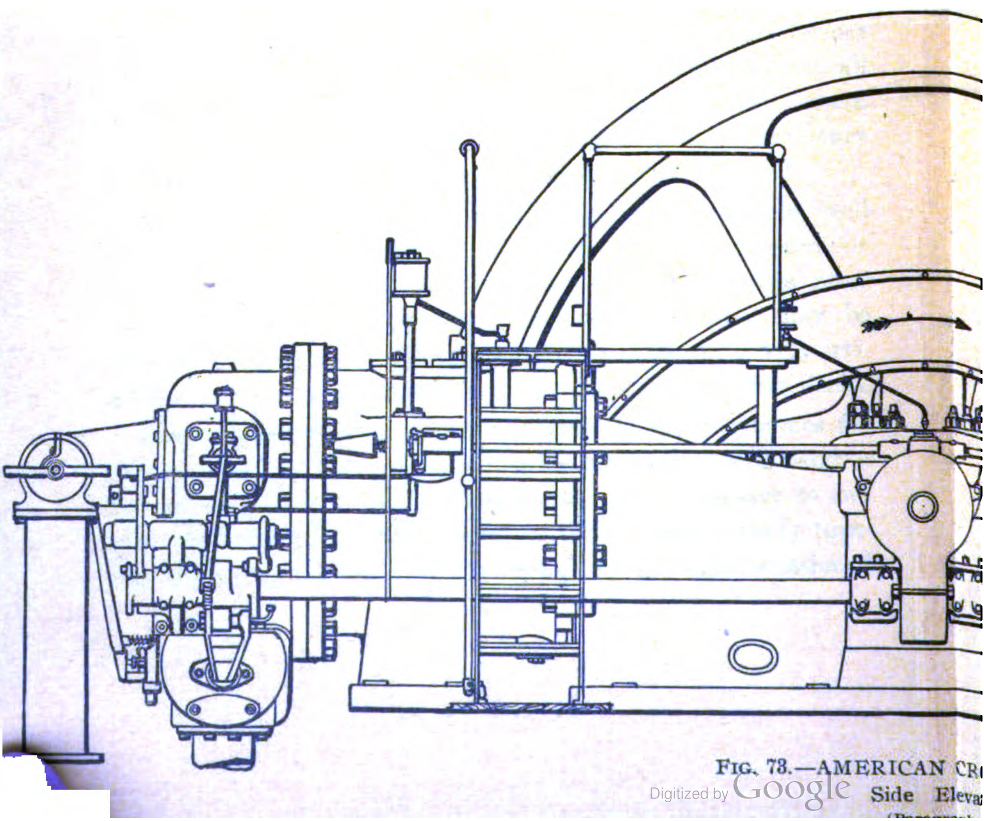
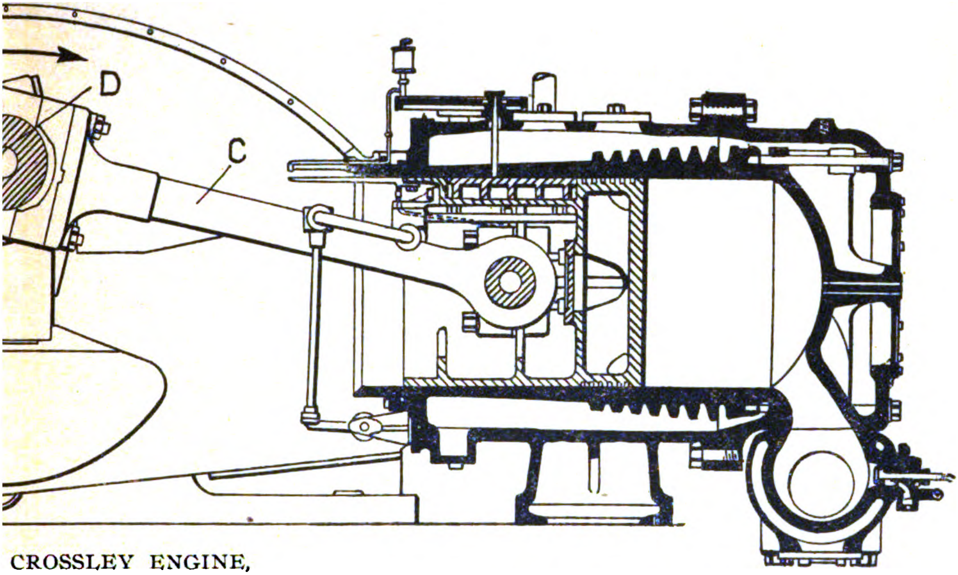


FIG. 73.—AMERICAN CR

Side Eleva



CROSSLEY ENGINE,
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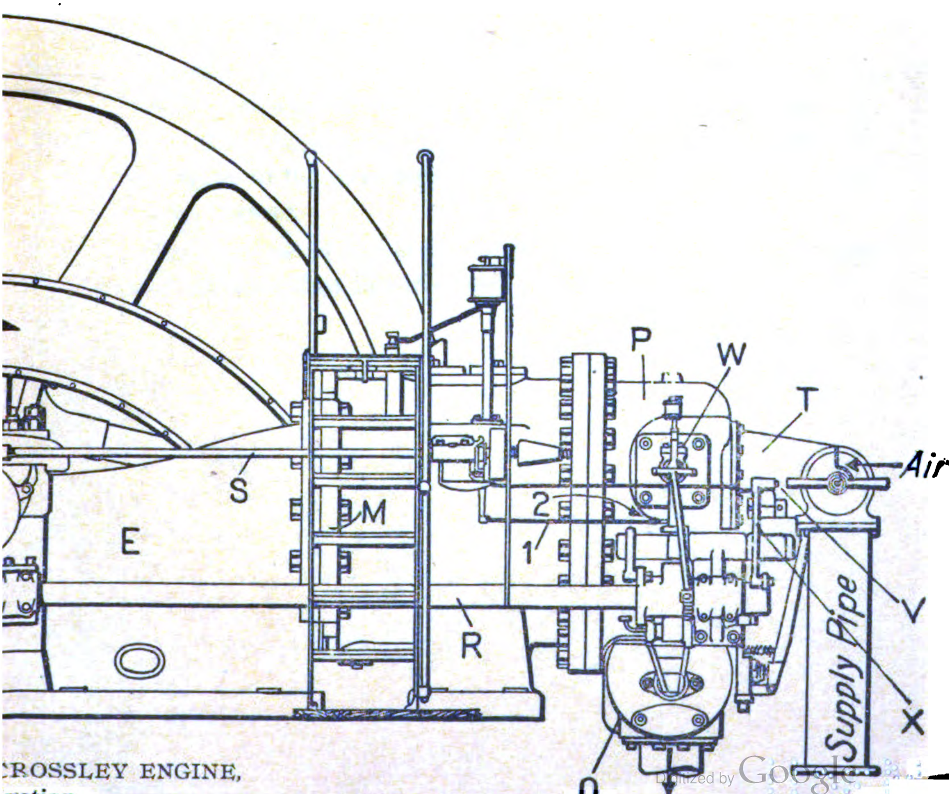

CROSSLEY ENGINE,
·vation.

by the explosion. With the latter arrangement, the slight slip of the belt may lessen irregularities.

For factories and shipyards, gas engines are very economical and convenient prime movers. A small engine may be fitted to each line of shafting or to each small department, rendering it unnecessary to run the whole of the plant when overtime is being worked. This would be especially valuable, say, where cylinder boring was being carried on, as the boring shop frequently has to run continuously, taking the finishing cuts through a cylinder. A separate gas engine may also drive the blower for the foundry cupola, making it unnecessary to maintain steam after the other departments have closed down. In each case, the small gas engine requires far less attention than the steam engine which it would replace, besides costing much less for fuel, and being far cleaner than any boiler-fed installation can ever be.

Another development consists in mounting an engine upon a platform on wheels, for use either as a portable or traction engine. For these purposes, however, it is usual to adapt the gas engine to the consumption of kerosene or gasoline, for very obvious reasons.

Applications of internal combustion engines to many purposes are described in subsequent chapters.

CHAPTER XVI.

FOUR-CYCLE VERTICAL ENGINES.

203. Vertical, Single-Acting Engines. Engines thus defined are built by the various manufacturers in single-cylinder, double-cylinder, or multi-cylinder types. The single-cylinder engines are usually made in sizes ranging from 1 to 15 horse-power, the double-cylinder from 15 to 50 horse-power, and the multi-cylinder from 50 to about 300 horse-power.

In general construction, the various makes resemble each other very closely. They are nearly all of the inclosed crank-case type, differing from each other mainly in the mechanical details of their working parts.

The machines described in this chapter are some of the most successful engines of this type, and have been here selected chiefly for the purpose of illustrating a few of the many possible arrangements under this style of construction.

204. The Walrath. The Walrath engines are built in one, two, and three cylinder units, of the vertical inclosed crank-case type.

Fig. 75, shows a two-cylinder direct-connected unit of 50 horse-power especially adapted for electric lighting, where close speed regulation is essential. Units developing more than 50 and up to 150 horse-power are usually built with three cylinders. *Fig.* 76, is a vertical cross-section through one of the cylinders showing the general construction of the cylinder, crank-case, piston, etc., and the positions of the various valves and actuating levers.

A—Water Jacket; B—Crosshead oil-box; C—Igniter; D—Valve Rocker; E—Valve Rocker-Arm; F—Exhaust Valve; G—Exhaust Manifold; H—Water Outlet; J—Exhaust Pot;

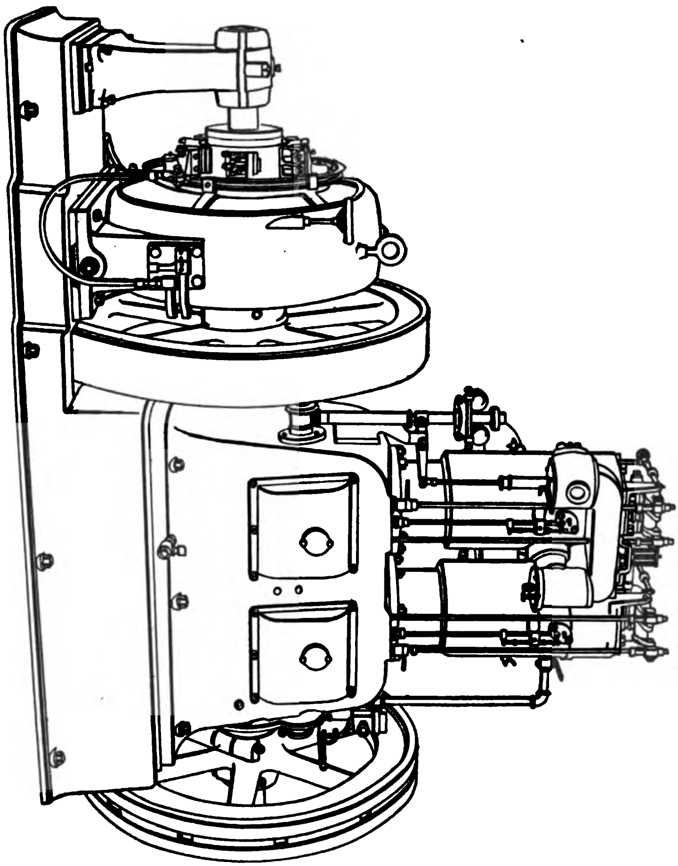

FIG. 75.—WALRATH ENGINE, 50 HORSE-POWER.
Two Cylinder Unit.
(Paragraph 204.)

K—Exhaust; L—Water Inlet; M—Igniter Trip-Arm; N—Radius Arm; O—Cam Shaft spur-wheel; P—Intermediate spur-wheel; Q—Rear Cover-Plate; R—Igniter Trip Rod.

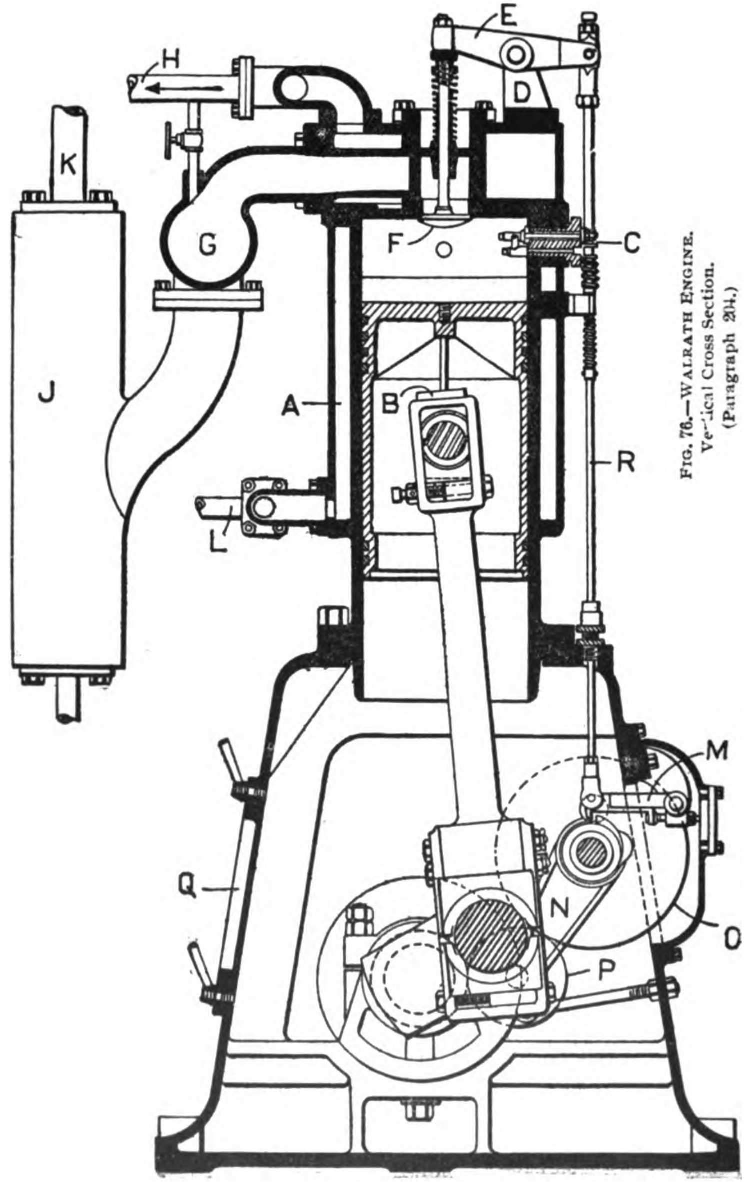

FIG. 76.—WALRATH ENGINE.
Vertical Cross Section.
(Paragraph 204.)

In general construction, the three styles are practically identical, differing only in the number and size of the cylinders. The base or crank-case is cast in one piece and bored to receive the cylinders, main and valve-gear bearings, the latter being removable and adjustable for wear. The closed crank-case provides automatic lubrication for all of the internal working parts, the connecting rod dipping into the oil contained in the bottom of the frame and thus splashing a copious supply into the cylinders and main bearings. Oil cups are also placed on the outside of the framing, the oil being led through suitable pipes to all the bearings, which tends to maintain the required level of oil in the base.

All of the engines work on the four-cycle principle, the valve mechanism consisting of a simple shaft driven by means of three spur-wheels, which, together with those employed for driving the governor, are the only ones required to operate the several cylinders.

The governor is of the fly-ball type and is placed at the end of the engine frame. It operates a piston valve, which regulates the amount of explosive mixture for each impulse, admitting just enough to maintain uniform speed under all variations of load, and giving an impulse every second revolution of the crank for the single-cylinder engine, every revolution for the two-cylinder, and every two-thirds revolution for the three-cylinder engine, irrespective of the load.

The igniter consists of a casting which holds two electrodes, the stationary electrode being insulated in the plug, while the movable electrode is operated through the vertical igniter stems by a cam on the valve gear shaft. The contact points are of platinum wire set in steel and capable of being removed without disturbing the electrodes in the plug. The entire igniter

arrangement is secured in place by two studs and may be quickly removed without disturbing the other parts of the machine.

These engines are capable of using any kind of fuel, natural or manufactured, such as producer gas, gasoline, distillate, kerosene, or crude oil.

The admission and exhaust valves are of the poppet type, and are operated mechanically. On all engines above, and including, 10 horse-power, double-cylinder type, both valves are placed in cages fitted into the cylinder head and provided with ground joints. As these valves extend through the head, it is possible to do away with any pockets or recesses in the combustion chamber, and thus facilitate the re-grinding of the valves whenever necessary.

Each cylinder consists of a separate casting, free to expand without any tendency to get out of alignment. They are completely water-jacketed, successfully keeping the temperature low enough to insure copious lubrication at all times.

The reciprocating parts are carefully counterbalanced, the balance-weights being attached to the shaft instead of being cast in the fly-wheels. The length of the connecting rod is equal to three times the length of the piston stroke, and each end is fitted with gun metal brasses which are capable of being readily adjusted for taking up wear.

All engines above 20 horse-power are provided with a starting device, consisting of an air compressor and tank. The starting valve is a simple piston-valve operated by a cam and suitable auxiliary parts, which, at the proper time, make communication with the air tank and transmit the pressure to the engine. The same valve then opens the port leading to the atmosphere and exhausts the cylinder of air. This action con-

tinues until an explosion occurs, after which the air is shut off and the engine is allowed to attain its proper speed on the energy derived from its own fuel.

The engines of the belted type range from 2 to 300 horse-power units, and those of the direct-connected type range from 8 to 300 horse-power units.

205. **The Nash.** The Nash gas and gasoline engines are all of the four-cycle type, and their proportions appear to have been very carefully worked out, with a view to the attainment of reliability and durability, the bearing pins, crosshead pins, rollers, cams, and other similar working parts being made of steel, hardened and ground to the proper size.

Fig. 77, is a vertical transverse cross-section through one of the cylinders, and *Fig.* 78, a similar cross-section longitudinally through the crank shaft.

It will be noted that the barrels and heads of the cylinders are completely water-jacketed, with all passages large enough to provide a sufficient quantity of water for the effectual cooling of the cylinder.

The pistons are of the usual trunk type, and the connecting rods are of sufficient length to insure only slight wear, even after long-continued working of either the piston or the cylinder.

The crank shaft is in one piece of forged open-hearth steel cut from the solid. It is machine-finished all over, and runs in adjustable gun metal bearings so arranged that each crank is provided with a journal on either side. The larger engines are fitted with pillow-block brasses which can be easily removed for examination and adjustment whenever necessary. These brasses are made of phosphor bronze, accurately turned, and the bearings hand-scraped to fit them. The two brasses

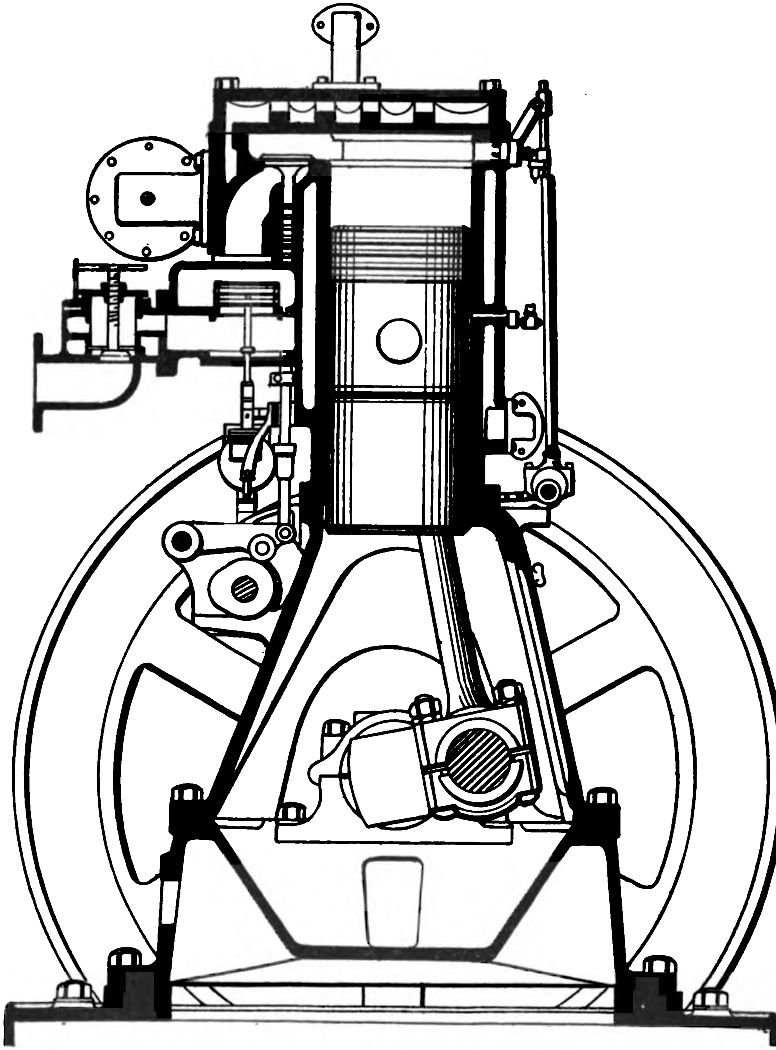

Fig. 77.—Nash Engine.
Vertical Cross Section.
(Paragraph 205.)

do not quite complete the circle, and the blank space thus formed on each side is filled with thin sheet steel liners. When it is desirable to take up wear, the cap nuts are taken off, the cap and brasses removed, and the shaft raised a trifle so as to allow the lower brass to be turned around the shaft and then lifted out. The liners or shims permit of taking up wear whenever necessary.

The connecting rods are also forged from open-hearth steel, the crank end being of the marine type with adjustable steps of a special hard bronze, the end of the rod being spread to receive the lower brass, while the upper brass and cap are held in place by bolts at each side.

The valves and the entire valve-lifting mechanism are located on the working side of the engine, thus permitting convenient access to all the exposed working parts. The valves are of the poppet type, and as the cylinder heads contain no working parts, the removal of the covers, whenever necessary, exposes the pistons and valves for inspection and cleaning.

A single cam shaft driven by a pair of spur gears operates all the valves through the medium of levers and rollers. Each cylinder has its own admission, gas, and exhaust valves actuated by its individual cam, roller, and lever; each also having a gas valve with a pawl engaging a toe carried on the admission-valve stem. By this arrangement, both of these valves open together for the purpose of admitting a charge, or else the governor acts, disconnecting the pawl, so that the gas valve remains closed and no charge is admitted until the normal speed has been restored.

The exhaust valve is located immediately behind the admission valve, and the exhaust connection appears behind the cylinder above the gas valve. Just below this is located the opening

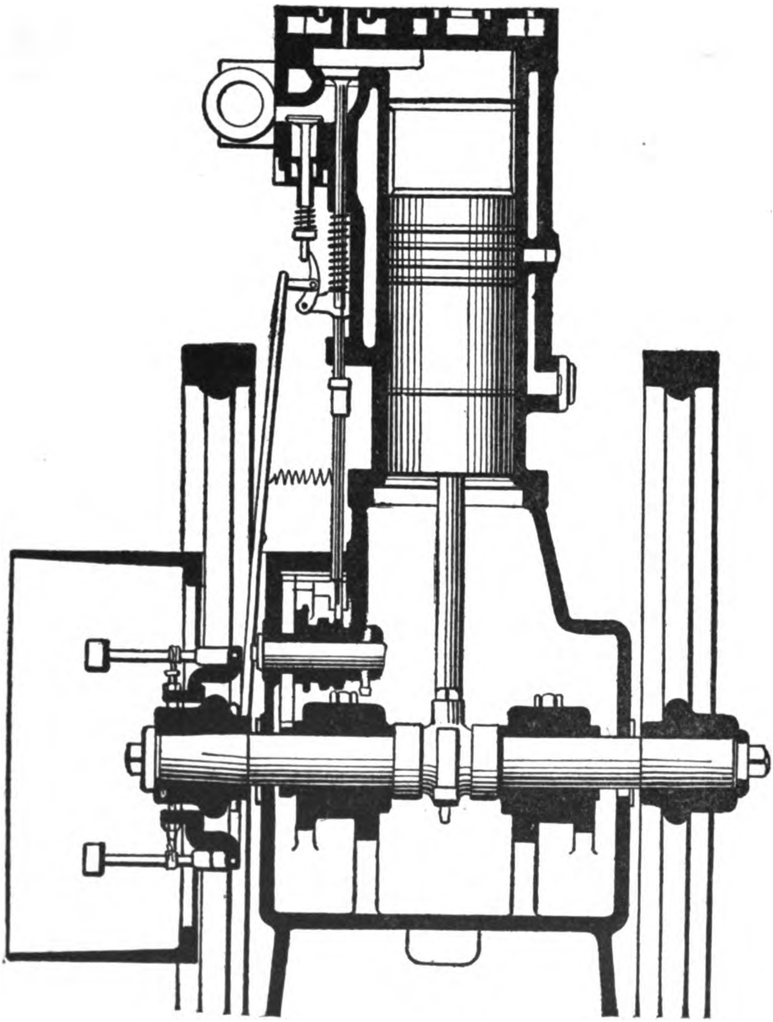

FIG. 78.—NASH ENGINE.
Vertical Longitudinal Section.
(Paragraph 205.)

by which the gas enters the mixing chamber, and, surrounding the upper part of the gas connection, is an annular opening through which the air passes and mixes with the entering gas to form the charge.

In the single-cylinder engine, the governor is a simple form of shaft governor. In the multi-cylinder engines, a special fly-ball governor operates by the method of missed ignitions. This governor does not operate the gas valves directly, but simply indicates by the position of a lever when the valves shall open or remain closed. Each cylinder is governed independently of the others.

When the throttling governor is employed, it acts on the common throttling principle by which a greater or lesser quantity of gas is admitted to the mixing chamber. The valve is actuated once during each cycle of each cylinder, but the quantity of explosive mixture is controlled by the action of the governor, the time of release of the valve and its fall determining the quantity of gas admitted to the cylinder.

Ignition is effected either by hot tube or electric spark. The hot tube is made of a special alloy of great durability and is heated by a Bunsen burner. The electric igniter can be operated from a battery, from an ordinary lighting circuit, or by means of a small generator attached to and operated by the engine itself. The electric igniter is secured in place at the top of the cylinder by two bolts, by loosening which, it can be readily removed whenever it becomes necessary to brighten the points which extend into the clearance space.

The single-cylinder engines range in size from 3 to 10 horse-power; the two-cylinder from 15 to 30 horse-power; and the three-cylinder machines from 40 to 150 horse-power.

206. The Westinghouse. The Westinghouse gas engines

are best known by those of the single-acting, vertical type, built in one, two, or three cylinder units. Recently, however, the manufacturers have developed a double-acting type which is specially adapted for central stations requiring generating units of high power. The double acting-type is not built in sizes below 200 horse-power, but continues the line of engine capacities beyond the present limit of the single-acting type so that the power units available in the two types range from 10 to 4,000 horse-power rated capacity.

The rating of these engines is based in all cases upon the brake horse-power. All engines are carefully tested previous to shipment, and are subjected to a series of performance tests, the records of which are always kept on file. The pressures usually carried with natural gas are approximately 350 pounds explosion pressure, 120 pounds compression pressure, and 30 pounds exhaust pressure. All types operate on the four-cycle principle. The verticle engines are built in two general styles; (a) two-cylinder for gas or gasoline; (b) three-cylinders in sizes up to 300 horse-power. For the smaller powers two-cylinder engines are used, and for medium powers the three-cylinder type, which is readily adaptable for generator driving, either continuous or alternating current, singly or in parallel.

The double-acting type will be found described in paragraph 213.

In the present paragraph *Fig.* 79, shows a general view of a three-cylinder engine, and *Fig.* 80, a cross-section through one of the cylinders.

The governing is effected by varying the quantity of the explosive mixture admitted to the cylinder, in proportion to the load on the engine, thus obviating the occurrence of idle strokes. The governor is mounted at the end of the engine on a short

vertical spindle geared to the main shaft. It is of the fly-ball type with knife edges and roller contacts.

These engines employ fly wheels of moderate weight, and speed control is accomplished within any desired limits by means of the governor. In the case of alternating-current generators operated in parallel, the system of governing employed,

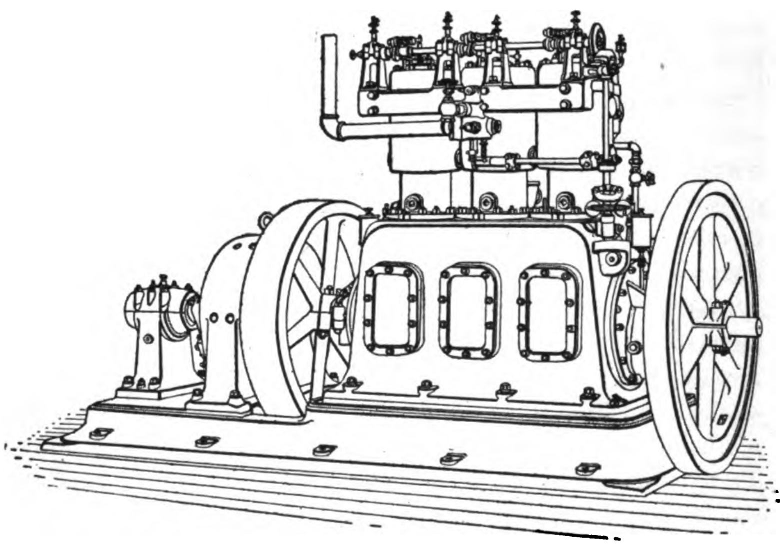

FIG. 79.—WESTINGHOUSE ENGINE.
Three-Cylinder Unit, 800 Horse-power.
(Paragraph 206.)

together with the multi-cylinder design of the engines, appears to give very satisfactory results in systems of low frequency, while for higher frequency and other special cases, a special type of coupling is provided, which gives a limited amount of flexibility to the engine generator drive.

The method of ignition in all types is by electric spark at

either high or low voltage, as may be desired. In plants where lighting current is available, the current can be taken directly from the mains and passed through incandescent pilot lamps, both for the purpose of limiting the current to the amount required and for indicating the continuity of the supply.

The most conspicuous features of the single acting type are the housed cranks, trunk pistons, roller-and-cam valve movement, adjustable and concentric journals, built-up cranks, and compressed-air starting devices.

Referring to *Fig.* 80, it will be noted that all the valve movements are accomplished by the single cam shaft, A, mounted within the housing. It is driven by a single reduction gearing directly from the main shaft, and upon it are mounted two sets of cams, one for operating the exhaust valve, and the other for operating the admission valve and the igniter. In each cylinder, a single cam is employed to operate both the admission valve and the igniter. The exhaust mechanism includes an auxiliary cam of opposite throw mounted loosely at the side of the main exhaust cam. This cam is thrown into engagement when the engine is started, and opens the valve at each stroke. The compressed air for starting is then admitted to one cylinder by the action of a special double-throw cam mounted outside the casing on the end of the cam-shaft so that this cylinder is allowed to operate temporarily as an air motor. During this operation, both the admission valve and the igniter of this cylinder are cut out of service by means of a clutch which is automatically operated by the compressed air system.

Fig. 80, also shows that all the working parts, both valves, and igniters, are contained in the cylinder casting, while the head is a plain cylinder cover cored out for circulating water.

A prominent feature of the design is the relative location of the admission valve, B, and the exhaust valve, D. These valves

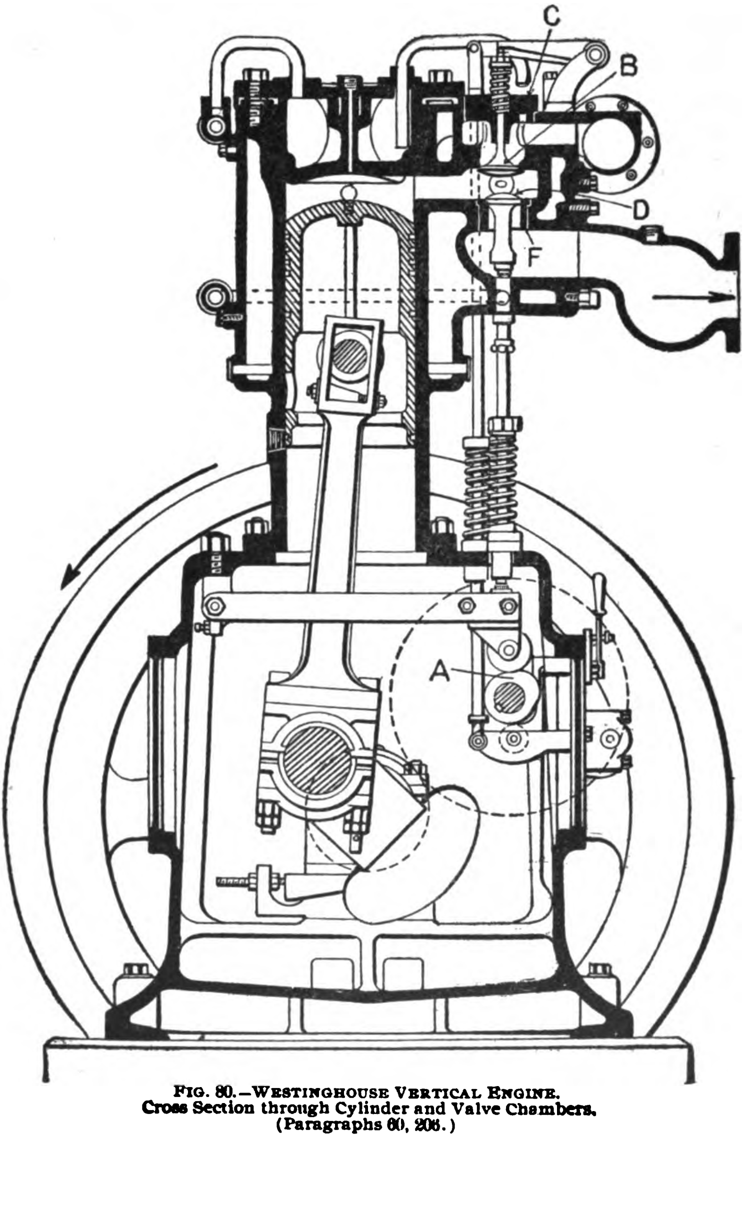

FIG. 80.—WESTINGHOUSE VERTICAL ENGINE.
Cross Section through Cylinder and Valve Chambers.
(Paragraphs 60, 206.)

seat vertically in opposite directions, are held in place by special springs, and are removable through the same opening in the casting. The admission valve is mounted in a bonnet, C, and may be removed in its entirety without dismantling, thus leaving room for taking out the exhaust valve, or its seat, F, if necessary. This arrangement tends to reduce the working temperature of the exhaust valve by causing the cool entering mixture to flow directly across the valve head. These conditions make it possible to use dry valves on comparatively large engines, but water-cooled valves are employed on all engines above 125 horse-power, and also in engines below this size when they are used for special purposes. The valves are of forged steel and are bored throughout the length of their stems, for the reception of a small copper water-tube through which the circulating water is conducted to the valve head, where it is discharged into a recess formed within the enlarged part of the valve, returning through the annular space between the tube and the spindle bore. In locations where cooling water is obtained from artesian wells, the valves used are of special design, made of cast iron.

The igniter is of the usual make-and-break type. It is removable in one piece in the form of a plug, and is operated by a vertical rod from the cam-shaft.

The mixing valves are of two forms, according to the character of the fuel gas. With natural or illuminating gas, quite free from solid or viscous impurities, a two-piece piston valve is employed, the vertical movements of which are directly controlled by the governor, so as to increase or decrease the port opening of each section in proportion to the load on the engine. With producer gas or other lean gases (such as blast furnace gas), a double-beat poppet valve is employed, and the proper

proportion of gas to air is secured by independent plug valves, each of which has graduated ports.

207. **The Meriam-Abbott.** In general construction, these engines are of the double-cylinder, vertical type, the cylinders working on the four-cycle principle. A transmission gearing is employed consisting of a vertical shaft, located at the rear of the engine midway between the cylinders, driving the secondary shaft by means of two to one bevel wheels. This secondary shaft is centrally located above the cylinder heads and carries both the valve cams and the igniter mechanism.

The four poppet valves—two for admission and two for exhaust—necessary for the operation of a double-cylinder engine, are located in a single head casting and open directly downward into the clearance space. By this form of construction, side pockets in the compression space are avoided and the amount of cooling surface reduced to a minimum.

Fig. 81, shows a 35 horse-power engine ready for mounting as a power generator, or to be directly connected to any standard make of electric generator of 20 kilowatts capacity. *Fig.* 82, shows the general arrangement of the system of ignition, the peculiar feature of which is the making and breaking of the primary circuit under a bath of oil.

In this system of ignition, the jump-spark method is employed, but there is no vibrator on the coil. The details of the device as shown in *Fig.* 82, consist of an oil cup, A, adjustable in the insulated sleeve, B, the tapered hole in the cup being capable of receiving an easily renewed taper pin. Contact is made between this pin and a spring rigidly fastened to the supporting framework, the entire arrangement being adjustable around its axis for the purpose of changing the time of ignition. The insulated terminals, C and D, in conjunction with the

rotating pin, E, serve to ground each cylinder alternately, thus permitting the use of a single coil and a single contact maker.

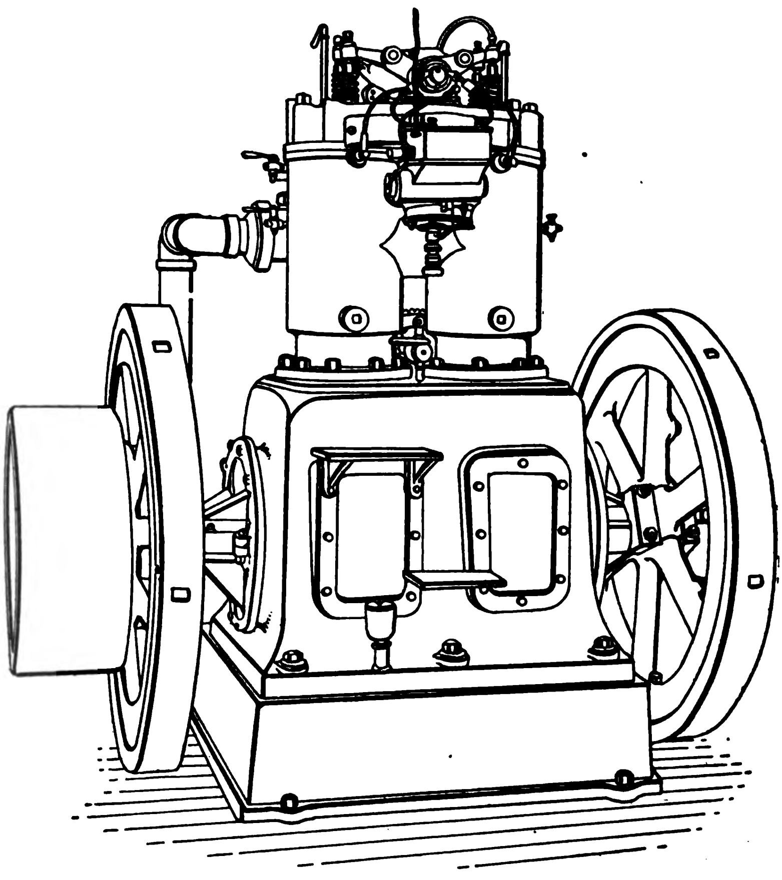

FIG. 81.—MERIAM-ABBOTT ENGINE.
Two-Cylinder Unit, 85 Horse-Power.
(Paragraph 207)

This system requires more current than the other forms of electric ignition, but is found to be very satisfactory for high-

duty service. Spark gaps are used at the plug terminals so that the spark is in sight while the engine is in operation. The only wearing part is between the two copper pins, and the wear on these can be readily taken up by adjusting the cup, A. No platinum is used in the system, and the cost of maintenance is very slight.

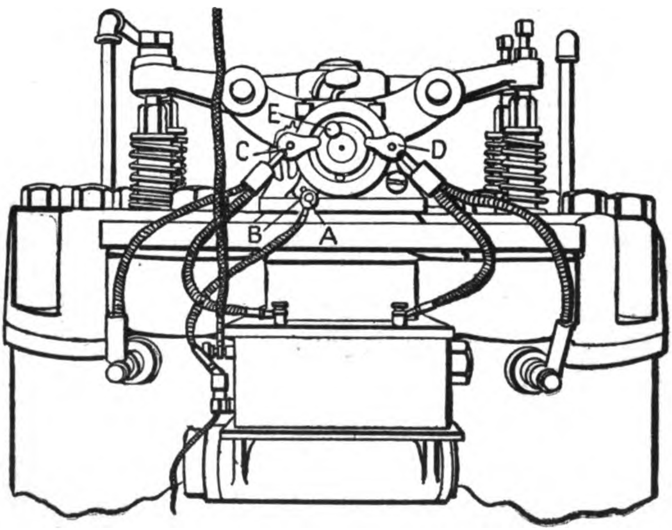

FIG. 82.—MERIAM-ABBOTT ENGINE.
System of Ignition.
(Paragraph 207.)

Another characteristic feature of this engine is the connecting rod which automatically adjusts itself for wear, by means of spring washers on the bolts, thus eliminating the necessity of taking it up from time to time, and insuring continuous running without knocking.

Compressed-air starters are used on all engines of 18 horsepower and over.

As has been stated, the primary electric circuit, on this particular engine, is made and broken by the contact and separation of two copper pins under an oil bath, thus preventing wear of their tips through sparking. The spark gaps, to which reference has been made, occur in the secondary or high-tension circuit, in addition to the spark gap, proper, between the ignition points of the plug itself.

It was found, by workmen of Panhard-Levassor, that an *outside* spark gap, in *series* with the jump-spark circuit, occasioned a much fatter and hotter spark between the ignition points. The device has been carefully worked out and ascertained to be an almost certain cure for weak or ineffective ignition due to uncertain battery action or other troubles, besides serving as a valuable indicator of the working of the igniting apparatus. About the only trouble likely to falsify the accuracy of its indications is the formation of soot or other deposit between the points of the spark plug.

CHAPTER XVII.

FOUR-CYCLE DOUBLE-ACTING ENGINES.

208. The Nürnberg. This engine has been designed especially for the use of blast-furnace gas, and, therefore, it is also well adapted to the perfect utilization of coke-oven gas, and various kinds of producer gas.

Up to the present time, it has been built in sizes ranging from 250 to 3,200 horse-power, but it is understood that the manufacturers are ready to build engines up to and exceeding 6,000 horse-power.

The engine has two cylinders placed tandem or one in front of the other, the four-cycle operations taking place at each end of either cylinder, thus giving the double-acting effect. This arrangement requires that each cylinder end be provided with three distinct valves. First, the inlet valve for admitting air or explosive mixture to the cylinder; second, the gas valve for regulating the amount and period of gas admission for each impulse; and third, the exhaust valve.

Fig. 83, gives a longitudinal section of the engine, showing the general arrangement of the interior and location of the valves. *Fig.* 84, is a cross section through the valve chambers. *Fig.* 85, illustrates the mechanism for operating the gas valves.

Referring to *Fig.* 84, it will be noted that the inlet and exhaust valves are of the poppet type, positively operated by a simple form of valve gear. The inlet valve opens about the time the crank reaches one dead center, and closes when it reaches the opposite one. The gas valve is operated by a governor-controlled mechanism illustrated in *Fig.* 85, the gear being that which is commonly known as the "*Marx*" patent

gear, which is specially adapted to the operation of the valves of large-sized steam and gas engines.

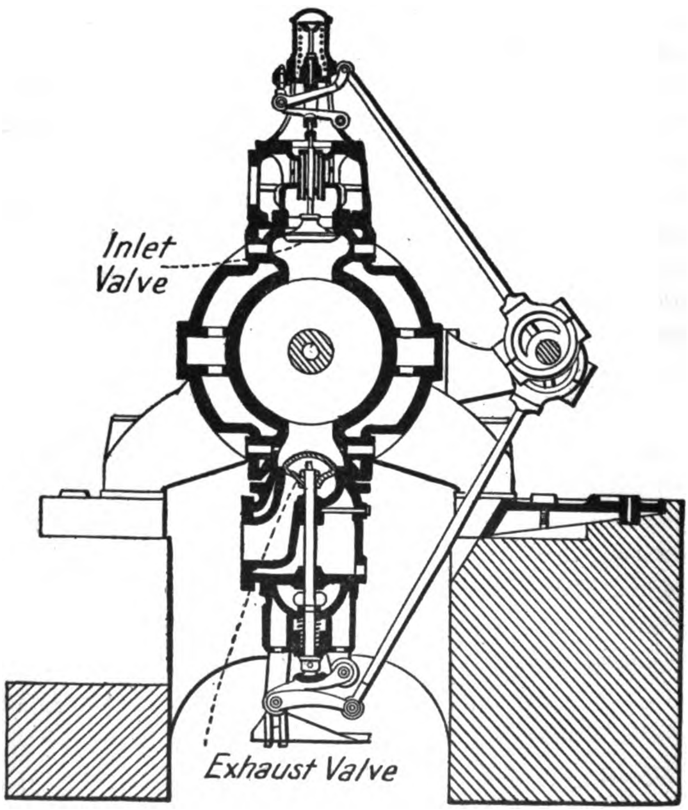

FIG. 84.—NÜRNBERG ENGINE.
Section through Valve Chambers.
(Paragraph 208.)

Referring to *Fig.* 85, it will be noted, that the forked rod, A, is actuated by an eccentric on the lay shaft; the upper end of A, being carried by the swinging link, B. The hook, C,

which engages the outer end of the rolling lever, D, is pivoted to the pin, E, and the inner end of D, is connected to the gas valve stem. The lever, F, is provided with a curved upper edge which supports the lever, D. One end of the lever, F, is fulcrumed upon a pin fixed in the valve bonnet, while the other end is raised and lowered by the arm, G, which is actuated by the governor through the arm, I. When the outer end of the lever, D, is depressed by the hook, C, the rocking motion imparted to D, lifts the inner end, and with it the gas valve, the hook releasing the lever at the end of the piston stroke. It will be noted, that as the outer end of the lever, F, is depressed by the governor, the motion of the lever, D, is modified to such an extent that the gas valve is lifted later in the stroke of the piston, so that by varying the position of the lever, F, the gas valve can be opened at any point in the stroke according to the demand and consequent speed of the engine, and the position of the governor. The gas valve opens with a quick action, and closes instantaneously, but it is easily seated or prevented from pounding by means of the dash-pot, J. The exhaust valve is opened by a simple rolling lever operated by an eccentric on the lay shaft.

By this entire arrangement, the air and mixing valves, as well as the exhaust valves, are operated and closed while the crank is close to the dead centers, and the gas valve is opened earlier or later in the stroke according to variations in the load, accompanied by a proportionate throttling of the gas.

It will be noted, that the exhaust valves are placed in the very lowest part of the cylinder, so that any dust carried into the cylinder by the gases, and any carbonized oil formed in the cylinders, will be swept out through these valves and not be permitted to collect and injure the pistons and cylinder walls,

Each end of every cylinder is provided with two distinct igniters, thus insuring perfect ignition and combustion of the gases, and providing a safeguard against mis-firing in case one of the igniters fails to act. Also provision is made, in the event of an injury to any valve, for cutting out of operation the end of the cylinder in which this valve is located, by shutting off the ignition and gas admission to that particular cylinder only.

All parts of the engine such as the cylinders, cylinder heads, pistons, piston rods, etc., are thoroughly water-jacketed or otherwise water-cooled, and all important moving parts are provided with pressure lubrication, the oil being automatically collected, filtered, cooled, and pumped through these parts so as to maintain a positive and continuous lubricating effect.

The piston rods are fitted with a special form of floating metallic packing, and the crosshead connections are so arranged that the cylinder covers may be slid off the rods without deranging this packing, whenever it is desired to overhaul the pistons. These lattter are provided with plain cast-iron spring rings.

The lay shaft with its eccentrics, the gear for operating the mixing valves, and all regulating devices, are located above the floor, thus being always in sight and easily accessible.

The construction of the entire engine and its supports permits of its free expansion lengthwise without in the least affecting its alignment. In all but the very largest sizes, the main frame and slide are cast in one piece.

These engines are built by the Allis-Chalmers Co., and are especially adapted to rolling mill and electric power-transmission installations, which, as a rule, require large power generating units.

209. The Blaisdell. This engine is a double-acting four-cycle engine having two power cylinders, A and B, placed tandem as shown in *Fig.* 86, and a compressor cylinder, C, placed tandem to the two power cylinders.

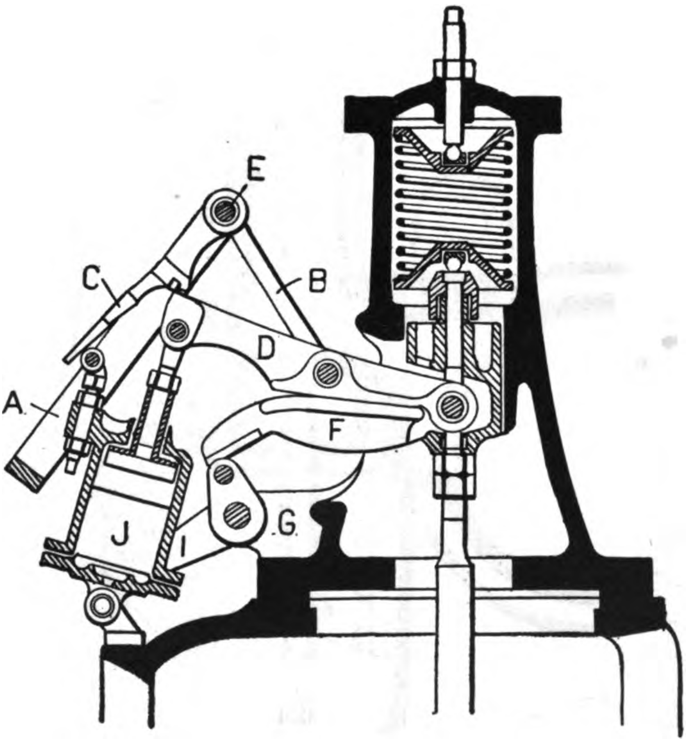

FIG. 85.—NÜRNBERG ENGINE.
Gas Valve Mechanism.
(Paragraph 208)

The tandem arrangement of double-acting four-cycle cylinders gives the same number of impulses as a double-acting steam engine, with equal uniformity of turning effort.

Fig. 87, is a cross section through the valves, and *Fig.* 88, a detail of the igniter mechanism.

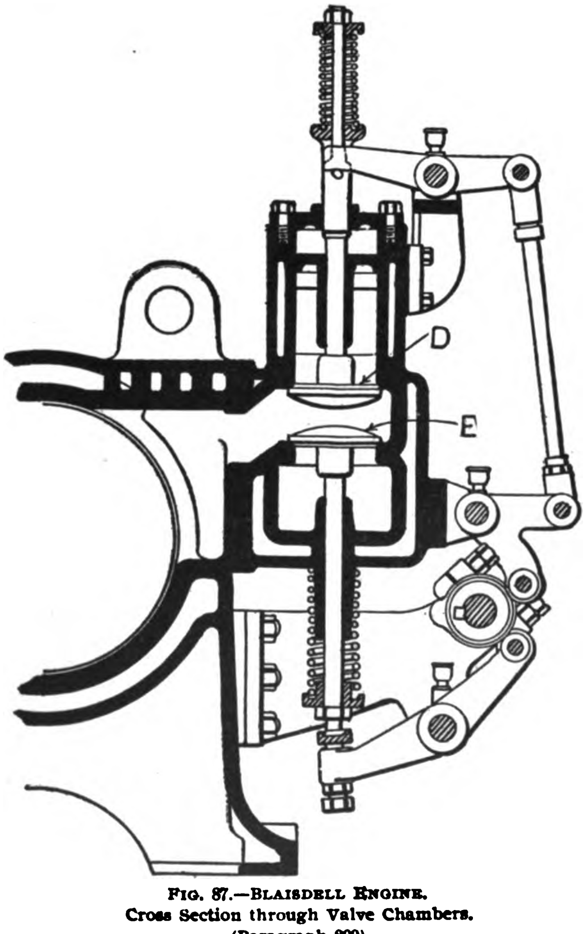

FIG. 87.—BLAISDELL ENGINE.
Cross Section through Valve Chambers.
(Paragraph 209)

Referring to *Fig.* 87, the valves are of the poppet type, working vertically, and are held to their seats by means of

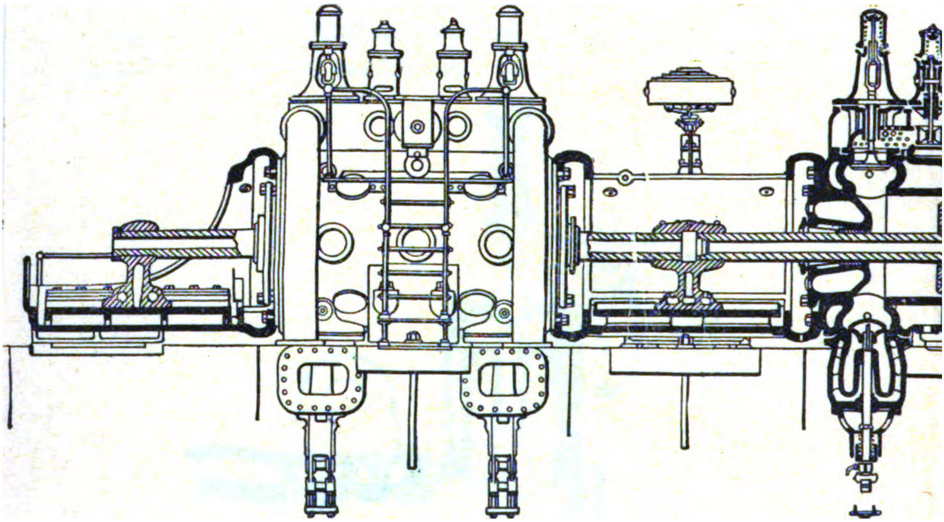

FIG. 83.—NÜRNBERG D
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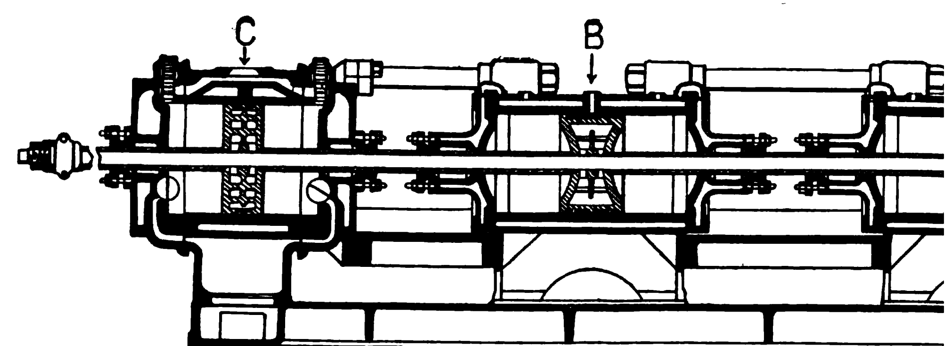

FIG. 86.—BLAISDELL DO
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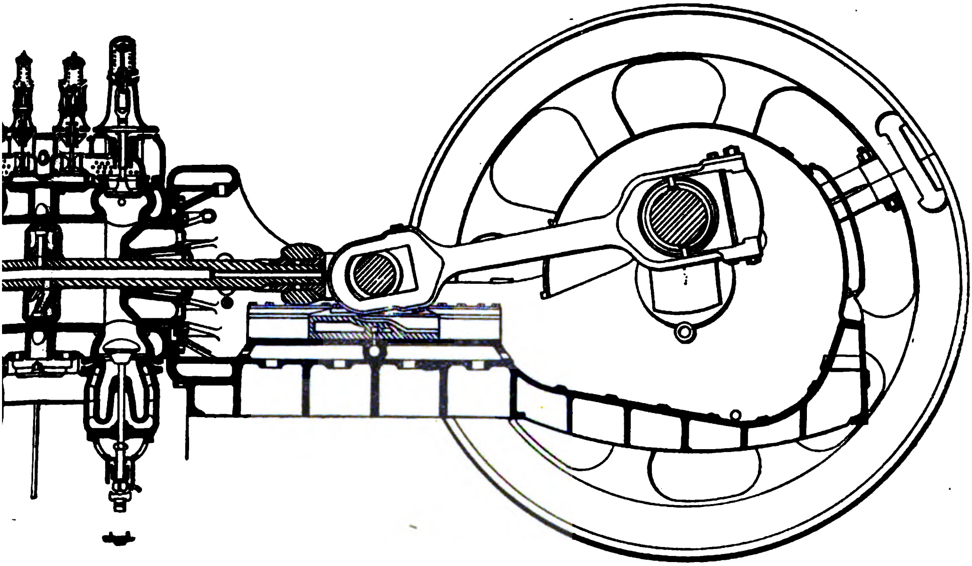

DOUBLE ACTING ENGINE,
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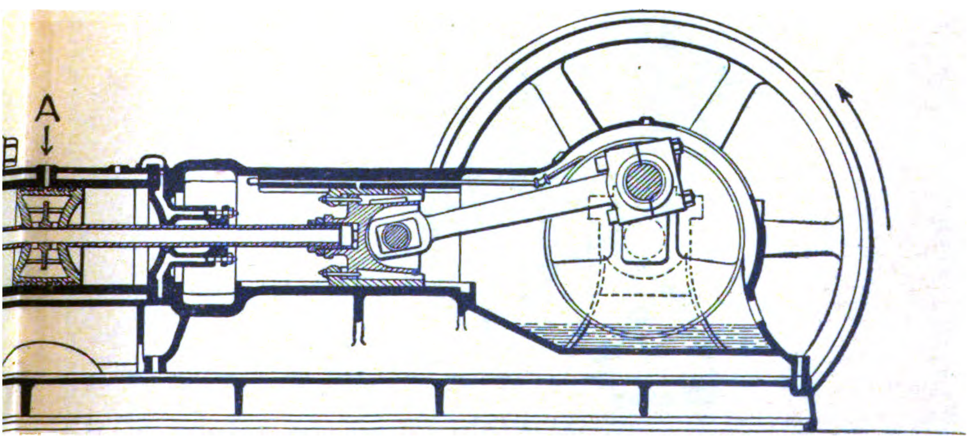

ıUBLE ACTING ENGINE,
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springs. The admission valve, D, is located immediately above the exhaust valve, E, thus causing the entering charge to pass directly over the head of the latter, keeping its temperature

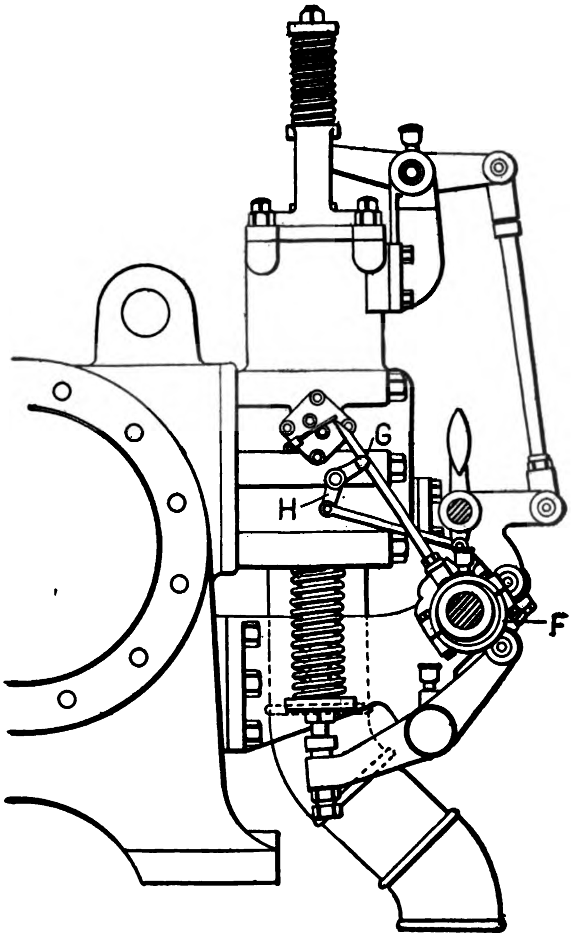

FIG. 88.—BLAISDELL ENGINE.
Detail of Igniter Mechanism. (Paragraph 209)

sufficiently low to render water-cooling unnecessary. The admission valve is placed in a cage as shown, which can be readily removed so as to expose the exhaust valve and permit its removal through the opening ordinarily filled by the cage.

Referring to *Fig.* 88, the igniter and valves are operated by a cam on the side shaft, a single cam being employed to operate both the admission and exhaust valves. The igniter mechanism is a special form of make-and-break contact operated by an eccentric, F, the rod of which rests in the small forked timing lever, G, forming one arm of the rock shaft, H.

The design is plain and substantial, provision being made for easy inspection and adjustment. The water-jacketing is very thorough, the tubular piston rods being under a pressure of 25 to 30 pounds. The crank, crosshead, etc., are splash lubricated.

The engine is started by means of compressed air, one cylinder being operated as an air motor until an impulse is obtained in the other cylinder, after which the engine continues to run on its own fuel.

210. The Cockerill. These engines operate on the four-cycle principle, and are built with one, two, or four cylinders, placed either single, tandem, twin, or twin-tandem. They are specially designed for the utilization of blast furnace gases, and are built in this country under license from the celebrated Belgian firm.

Fig. 89, shows a general view of a 500 horse-power tandem engine. *Fig.* 90, is a cross-section through one of the cylinders, showing the valves and valve gear.

Admission is effected by means of valves operated by cams keyed to the side shaft, which makes but half the number of

revolutions of the main shaft. Governing is effected by means of a centrifugal governor controlling either the quantity or the quality of the charge. If the first, the admission of a constant mixture is automatically cut off or throttled, resulting in variable compression. By the second method, the mixing valve is open throughout the charging stroke, the gas valve opening later than the others, at a point determined by the governor. This varies the relative proportions of air and mixture, giving constant compression, which is desirable for engines connected to dynamos.

The valves of each cylinder-end are operated by a single cam, thus requiring only a total of eight cams for a four-cylinder engine.

Referring to *Fig.* 90, the operation of the valve gear may be explained as follows: The side shaft, A, which is driven by the engine shaft, makes one revolution to two of the latter, and carries a cam, B, for each cylinder end. This cam revolves in the direction indicated by the arrow and operates both the admission and exhaust valves.

When the lobe of the cam begins to act on the roller, C, the latter and the rod, D, rise, the lever, E, oscillates, and its end, F, descends. This movement causes the mixing valve, G, and the air valve, H, to open, the latter, which is fixed to the mixing valve, uncovering the air ports, I. The time of opening of these valves corresponds exactly to the dead center position of the piston at the beginning of the suction or charging stroke.

During the first part of the stroke, air only is allowed to enter the cylinder. The double-beat gas valve, J, which is concentric with the mixing valve, remains closed. It is operated by the lever, K, the outer end of which, L, engages with the latch, M, of the lever, N, when the admission valves

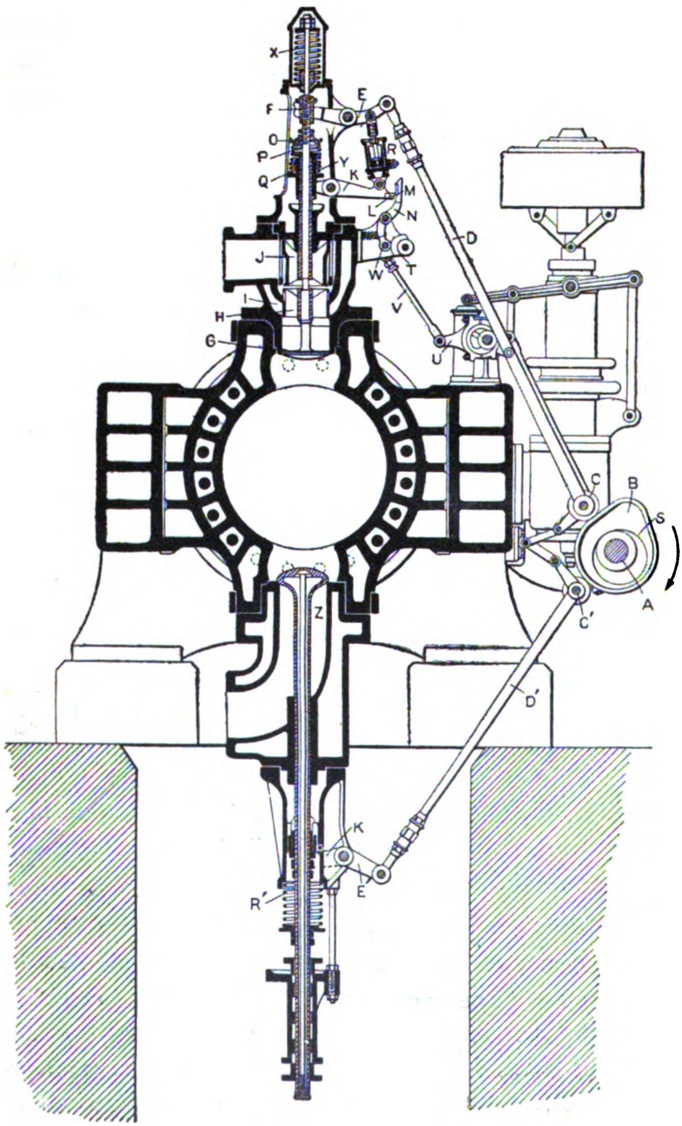

FIG. 90.—COCKERILL ENGINE.
Cross Section through Cylinder and Valve Chambers.
(Paragraph 210)

are on their seats. When the mixing valve opens, the spring cap, O, fastened to its stem compresses the spring, P, as the spring cap, Q, on the other end is fastened to the hollow stem of the gas valve, which, being blocked by the latch, remains closed. The connection, R, and its parts, act as a link of variable length between the levers, E and K.

An eccentric, S, on the side shaft, A, operates a small cam, T, by means of the rod, D, the oscillating lever, U, and the rod, V. The center of oscillation of the lever, U, is variable and controlled by the governor, and the effect of the displacement of this center is equivalent to a change in the length of the rod, V. The cam, T, operating on the roller, W, secured to the end of the lever, N, disengages the latch, M, at a definite moment predetermined by the action of the governor, and the gas valve, J, opens quickly, the amount of opening being limited by the space between the piston and the bottom of the dash pot, R. The proportions of the levers, E and K, are such that the opening of the valves, J and G, and also the air valve, H, bear a fixed relation to each other. From the moment the gas valve opens, as predetermined by the position of the piston during the suction stroke, both air and gas in proportions to give a good mixture are admitted regardless of the moment of cut-off.

The three valves remain open until the end of the suction stroke. At this instant, while the roller, C, descends on the lobe of the cam, B, the large spring, X, closes the mixing valve and the air valve, and the link, R, returning to its original length transmits the descending motion of the levers, E and K, and closes the gas valve. A small spring, Y, is employed for the purpose of allowing the mixing valve to continue its motion and seat itself in case the gas valve shuts first. The admission

and exhaust ports of the cylinder now close, and the charge is compressed by the return stroke of the piston.

A little before the crank reaches its outer dead center at the end of the expansion stroke, the lobe of the cam, B, touches the roller, C′, and acts by means of the rod, D′, and the levers, E′, and K′, and opens the exhaust valve, Z. This valve remains open during the exhaust stroke, and is closed by means of the spring, R′, when the crank reaches its inner dead center at the beginning of the next suction stroke, the spring always tending to close the valve and press the roller, C′, against the cam, B.

The cylinders are supported within a cradle formed in the framing, one end only being bolted to the bed-plate, thus permitting free longitudinal expansion. The cross head guides relieve the cylinder walls of the weight of the pistons and rod. The cylinders, heads, exhaust valves, and pistons are all water-cooled, the piston-rod nut also, as a preventive of premature ignition (Par. 309).

The engine illustrated is started by an explosion of carburetted air charged by a gasoline carburetter, the fly-wheel being turned round to compress the charge. Large units have a special compressor, furnishing compressed air for starting purposes. The turning of the engines is effected by an electric motor or hand worm-and-ratchet gear acting on teeth in the fly-wheel rim.

The gas used in these engines requires to be carefully purified and cooled. It is desirable that it should be completely cleansed from tar and naphtha, and it ought not to contain more than one-thirtieth of an ounce of dust per cubic yard. The best results are obtained when the admission temperature is not greater than 75° Fahr. With a higher temperature, the power developed will be reduced proportionally with the

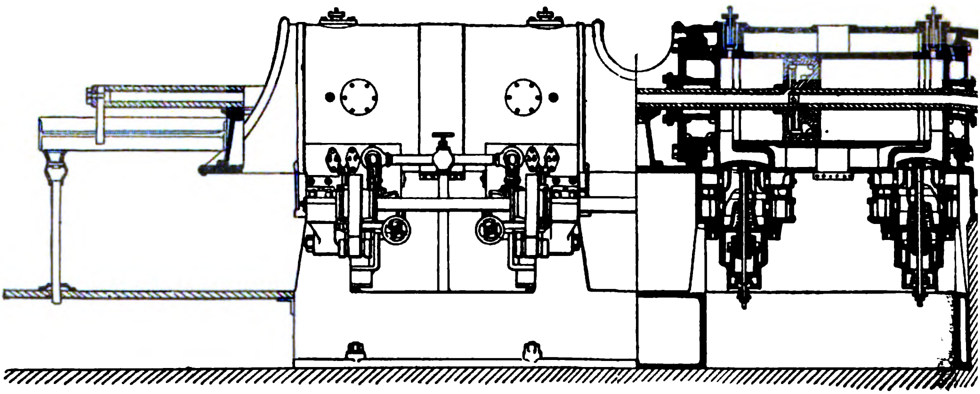

FIG. 91.—SARGENT TANDEM CYLIN

Longitudinal

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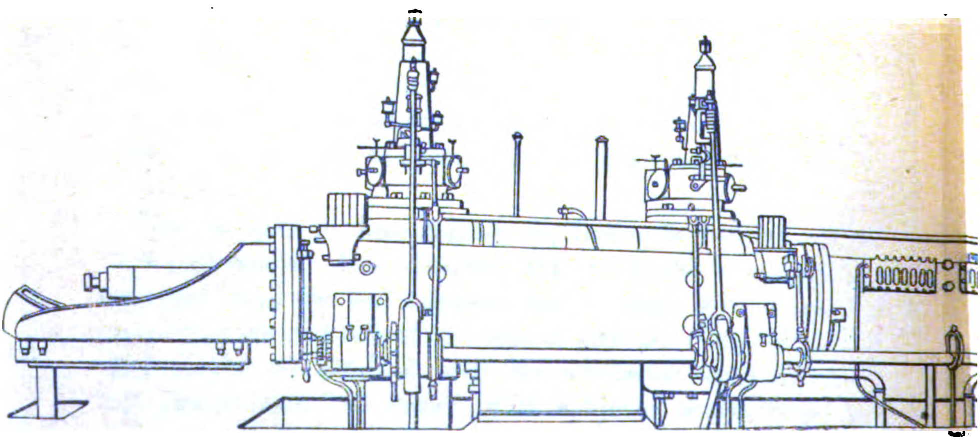

FIG. 89.—COCKERILL TAN

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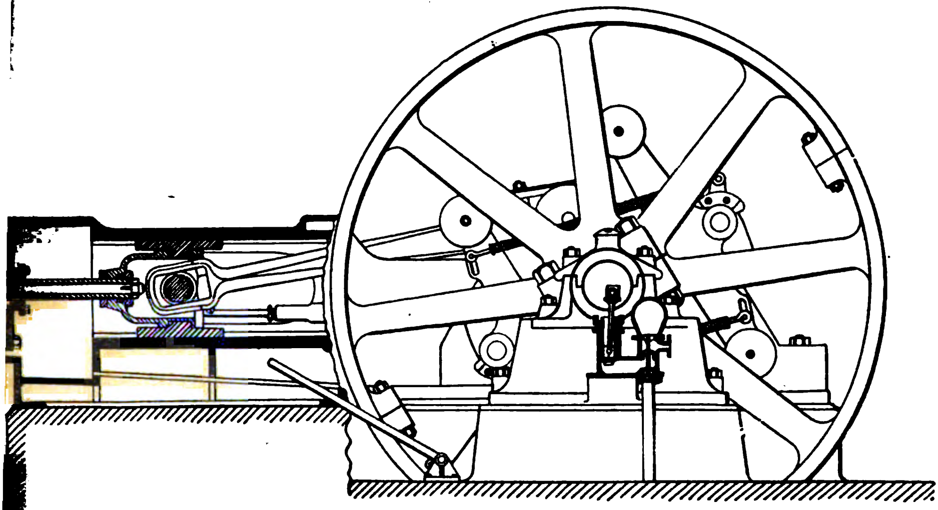

DER DOUBLE-ACTING ENGINE,
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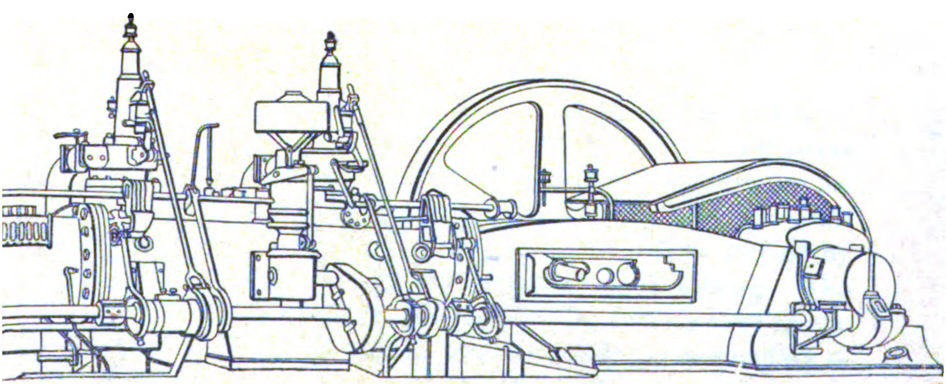

EM CYLINDER ENGINE,
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lowered density of the gas. A larger proportion of dust than the amount specified, is liable to produce serious cutting in the cylinders.

The gas consumption depends upon its quality. A heat consumption of 10,000 B. T. U., per brake horse-power, and a thermal efficiency of 25 per cent. at the rated capacity of the engine are guaranteed by the manufacturers.

These engines are built up to 600 horse-power for each single-acting cylinder or 1,200 horse-power for each double-acting. Thus a twin-tandem double-acting unit may develop 5,000 horse-power, with a speed regulation comparable to that of large steam engines.

211. **The Snow Engine.** Among the larger sizes of gas-engines, the Snow has been eminently successful. This is a double-acting engine working on the four-cycle principle; two cylinders being usually arranged tandem fashion on the same piston rod so as to give an impulse at each stroke as in a steam engine. These engines have been constructed to use natural and city gas, also oil-gas from crude petroleum, as well as that generated by bituminous or anthracite producers.

The gas and atmospheric air are drawn, by separate passages, into a manifold extending the length of the cylinders; this serves as a mixing chamber, and from it the admission valve of each cylinder-end draws its supply of mixture for the charge. The admission valves are positively operated by means of cams on the half-speed shaft, but the cut-off is effected by an annular sleeve within the admission valve seating. The position of the governor arms controls the detents holding the cut-off sleeve and release the latter at a point corresponding to the demand for power. By this means the arranged propor-

tions of air and gas remain constant in the charge, whatever the power exerted, and there is no waste of unused charges as in a missed-ignition governor.

Closing the inlet before completion of the suction stroke expands the charge within the cylinder, so compression does not begin until the piston has returned to the point where the cut off was made. By these means the exploded charge is made to work expansively in the latter part of the working stroke, giving the same effect as the Atkinson Cycle, without the mechanical complexity of the Atkinson design (Paragraph 217). That this reduced compression does not create ignition troubles is shown by one of these engines having run successfully on a load factor as low as five per cent. The same engine —using producer gas—had a consumption of 2 lbs. fuel per kilowatt-hour, which is equal to 1½ lbs. per brake-horse-power-hour and shows great economy under the load conditions.

The governor is of a novel spring-loaded type, its weighted arms being connected by a horizontal bar which is threaded through them. Springs abutting against adjustable collars on the end of this bar serve as loading to the governor, and this arrangement causes the weights to follow a parabolic path, making the governor isochronous. Ignition is effected by means of a jump spark device, the electric current being supplied by a magneto.

The exhaust valves are controlled by cams on the half-speed shaft, and are water-cooled. The water-jacket service is very complete, including both heads of each cylinder, as well as the barrel. By means of telescopic or vibrating devices, water circulates through the piston rod and cross head, passing down a central pipe through the tubular rod and returning through the annulus around the pipe.

Forced feed lubrication is supplied to all working parts by means of mechanically operated pumps, and a series of tubes, leading to the crank-pin and cross-head-gudgeon, as well as to the stationary bearings.

These engines are chiefly made in the larger sizes. In one power-house in San Francisco there are four twin-tandem units each directly connected to a 4,000 kilowatt alternator, thus developing 5,400 brake horse-power for each set. This constitutes the largest gas engine installation at present in the world.

212. **The Sargent.** This engine is of the double-acting, tandem cylinder type, and is built in sizes up to 250 horse-power.

Fig. 91, gives the general design of the engine, and *Fig.* 92, a cross section through one of the cylinders, showing the valves.

Referring to *Fig.* 91, it will be noted that the sub-base extends from one end of the engine to the other, and is bolted to the foundation. The cylinders, fastened to the main frame, can slide back and forth upon the hollow supports rising from the sub-base, as the temperature varies. These supports maintain the alignment of the cylinders, and also convey the gas and the air from the hollow divided sub-base to the explosion chambers.

In this engine, the admission of the charge at full load is cut off from five-eighths to three-quarters of the charging stroke, according to the quality of the fuel used, which after compression and ignition is expanded to the cylinder volume, and released a little above atmospheric pressure at a temperature of about 400° Fahr.

The mechanism is comparatively simple, and avoids the employment of a multiplicity of valves and levers. A side shaft,

driven by a crank shaft and governor through worm gearing running in oil, and carrying two cams for each explosion chamber, one for the igniter and one for operating the valve, comprise all the moving mechanism except the valves and levers.

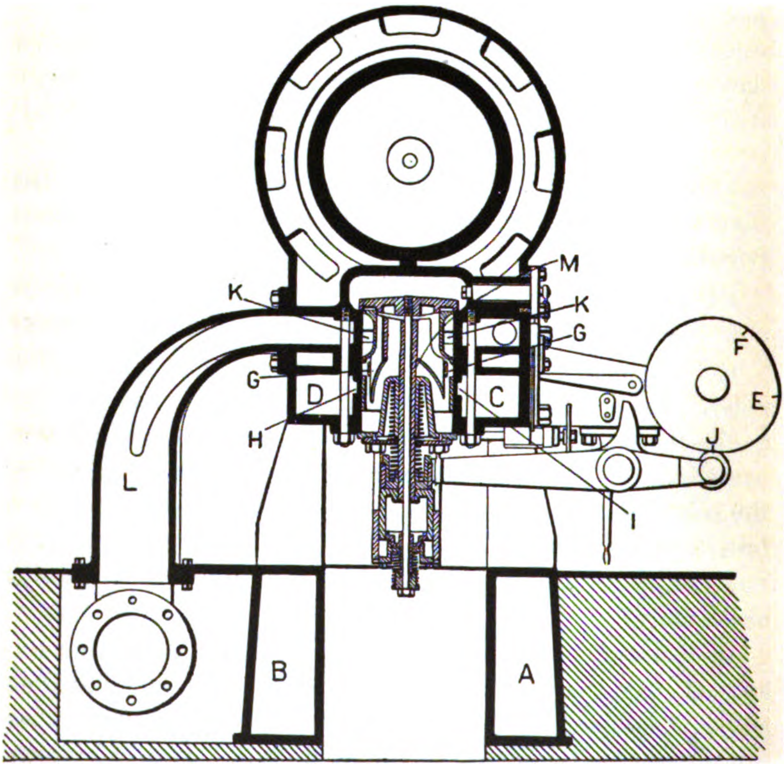


Fig. 92.—Sargent Engine.
Cross Section through Cylinder and Valves.
(Paragraph 212)

Referring to *Fig.* 92, the general operation of the engine may be briefly described as follows: Gas is admitted to the

chamber, A, in the sub-base, and air to the chamber, B, each passing through the cylinder supports to the chambers, C and D, above, ready to enter into the mixing chamber when the depressed portion of the cam, EF, passes the roller, and the ports, GG, in the piston valve register with the ports, H and I, in the bushing. When the piston valve is depressed to this position, the confined air in the piston valve dash-pot forces the poppet valve open, and allows the free admission of the charge. When the point, F, of the cam reaches the roller, the latter is forced down, while the other end of the lever goes up, carrying with it the piston valve, which cuts off the admission. The poppet valve then seats, and both valves remain in the normal position during compression, ignition, and expansion, or until the point, J, on the cam pushes the roller down and the piston up, which opens the poppet valve and allows the exhaust gases to pass out through the ports, K, and the elbow, L, to the exhaust pipe under the floor.

The poppet valve seals the opening in the combustion chamber during compression and explosion, and the piston valve, released from pressure, works loosely in its bushing, thus cutting off the admission and guiding the exhaust.

As the poppet valve controls the entering as well as the exhaust gases, both valves and their seats are kept cool and do not require re-grinding more than once or twice a year. Through revolving the piston valve by means of the index wheel, the blind post, M, varies the mixture according to the calorific valve of the gas.

The speed is controlled by a Rites inertia governor, attached to the fly wheel, and operates by advancing the rotation of the valve shaft relatively to the crank-shaft as the speed increases, thus reducing the mean effective pressure with the load. As the

load decreases, the cut-off occurs earlier, and a lesser quantity of a constant mixture of gas and air is admitted into the cylinder; but, as the amount of the products of combustion in the clearance space remains the same, the mixture grows weaker and weaker, and the combustion slower. The time of ignition advances with the cut-off, becoming earlier as the mixture grows weaker, thus maintaining the highest pressure at the beginning of the stroke regardless of the load on the engine.

Cylinder lubrication is effected by a force feed pump or check-valve lubricators; the valves receiving sufficient lubrication from the cylinders. The side shaft and board bearings are self lubricating. The cross head guides, crank pin, and main bearings, which require thorough lubrication at all times, are copiously oiled by the worm gearing which acts as a pump.

Each combustion chamber contains two electric igniters, placed so as to be surrounded with a pure mixture at the time of ignition, thus reducing to a minimum the possibility of a miss-fire on account of a mishap to either of them.

Starting is effected by compressed air. When the air pressure is turned on in one cylinder, it puts the starting mechanism into operation, and that cylinder acts as an air motor until the other cylinder begins to run on its own fuel.

All parts of the cylinder walls, heads, piston rod, and pistons are thoroughly water-jacketed. All valves, levers, timing screws, and other parts requiring adjustment, are readily accessible, and every part of the working mechanism is located above the floor, but yet below the center line of the engine.

The time of ignition and the proportion of gas and air in the charge may be changed while the engine is in operation.

All combustion chambers are readily accessible by simply removing the cylinder heads, without any further dismantling of the engine.

213. **The Westinghouse.** In general construction, the double-acting Westinghouse engines embody the essential characteristics of the single-acting type described in paragraph 206; starting, governing and ignition being effected in the same manner as in the vertical type.

In the horizontal engine shown in *Fig.* 93, the construction from crank to cylinders is similar to that of a horizontal steam engine, but the design and construction of the cylinders, pistons, and valves conform to the best gas engine practice. The cylinders are double-walled with the outer walls split peripherally so as to permit of independent expansion and contraction during operation, and to relieve the stresses developed during the cooling of the casting. All cylinder heads are cored out for cooling-water circulation.

The valves are of the poppet type. Straight ports at the ends of each cylinder communicate with the combustion chambers, which are cast integral with the cylinders. The relation of admission and exhaust valves is quite similar to that of the single-acting type. The cylinders, combustion chambers, exhaust passages, pistons and piston rods are all water-cooled.

The pistons are fitted with spring packing rings; they are secured in position on the piston rods by lock nuts, and present plain convex surfaces to the burning gases. The piston rods are made of nickel-steel; they are hollow, affording the means of introducing cooling-water to the pistons, and are packed by metallic self-centering glands. The water enters at the cross head through a telescoping pipe connection and finally emerges

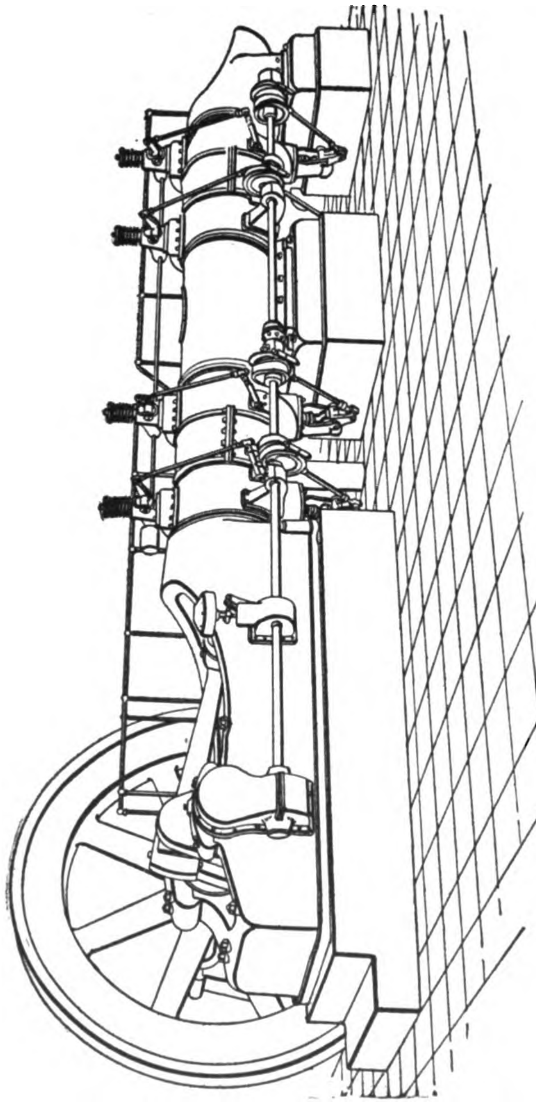


FIG. 98.—WESTINGHOUSE DOUBLE-ACTING ENGINE.
(Paragraph 213)

through a bronze tail-rod which passes through the rear cylinder head into a cast iron jacket piped to the discharge main.

The cylinders and packing glands are lubricated automatically by multi-plunger pumps driven from the valve mechanism.

It has been demonstrated that the waste gases from blast furnaces can generate six times as much power, when utilized in a suitable explosion engine, as they would when burned under boilers to generate steam. The great difficulty attending the use of this fuel lies in the presence of about 5 per cent. of very fine dust, besides moisture from the ore. This necessitates preliminary settling of the gases; washers to remove any remaining dust; condensers to take out moisture; scrubbers to extract ammonia; filters of sawdust or other material to eliminate any other impurities; and holders to store the purified gas against the needs of the plant.

Blast furnace gas varies in composition, according to the ore and fuel employed, but may be taken as averaging,

CO	24.0
CH_4	1.0
H	7.0
CO_2	9.0
N	59.0
	100.0 by volume.

This gas has a calorific power of about 110 B. T. U. per cubic foot. One volume requires to be mixed with 1.13 volumes of air in forming the charge for an internal combustion engine.

Extended trials have shown the possibility of generating one horse-power-hour with the consumption of little more than 1 pound of fuel in the blast furnace, a result only approached by the very best steam engines, while the iron is smelted free of any fuel charge.

CHAPTER XVIII.

TWO-CYCLE ENGINES.

214. **Single and Double-acting Two-Cycle Engines.** The general working principle of this type of engine is fully described in paragraph 61. They were first proposed by Clerk and other English manufacturers, and were produced by them in small sizes. The recent discovery, however, that gases of low heating value, such as those given off by blast furnaces, could be effectively used in gas engines, together with the increasing demand for large engine units upwards of 1,000 horse-power, has led to the development of large and successful engines of this type, of both the single-acting and double-acting patterns.

Of the larger engines, the Koerting double-acting appears to be the most important, and serves very satisfactorily for the purpose of illustrating the salient features of the highest development of the type.

215. **The Koerting.** These engines are built in both the four-cycle and two-cycle types, in capacities ranging from 50 to 3,000 horse-power, and are designed to operate on natural, producer, coke-oven, or blast furnace gas.

Referring to *Fig.* 94, which shows the side elevation of a Koerting double-acting two-cycle engine; *Fig.* 95, a sectional plan; and *Fig.* 96, a cross section through the suction valve; the operation of the engine may be briefly described as follows:

Since the engine is double-acting, the crank end and the head end of the cylinder are similar, and the admission valves are

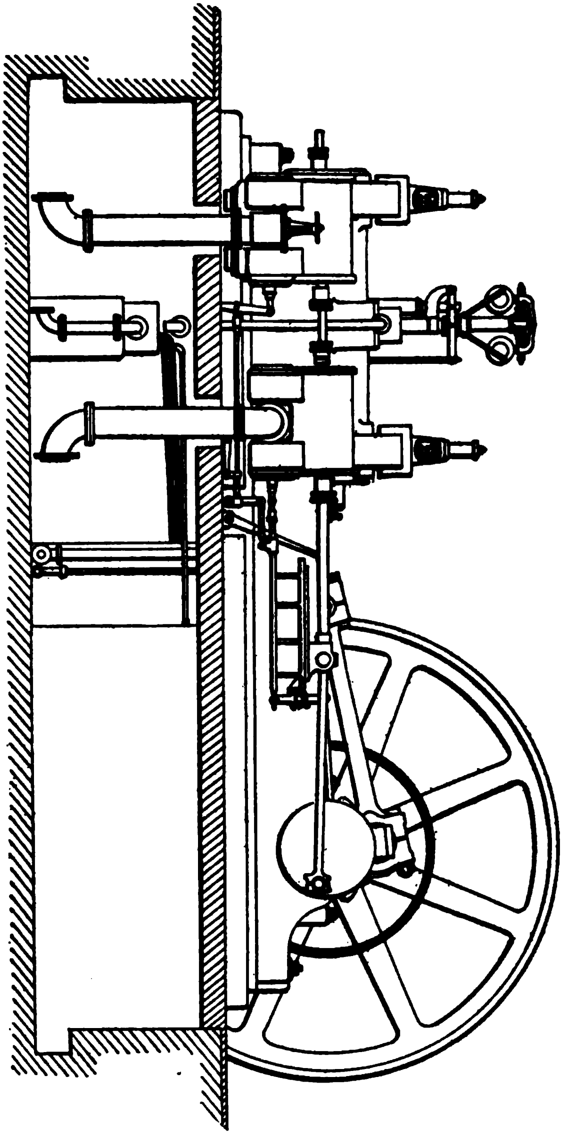


Fig. 91.—Koerting Two-Cycle Double Acting Engine. Side Elevation. (Paragraph 215)

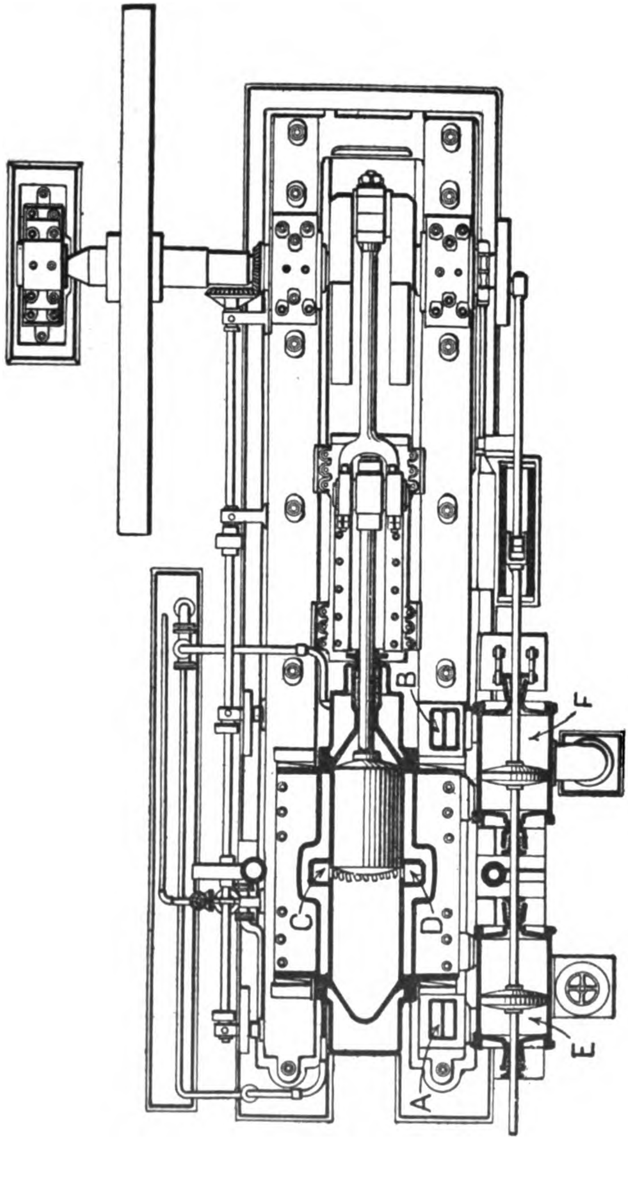


FIG. 95.—KOERTING ENGINE, Sectional Plan.
(Paragraph 215)

located in the valve boxes, A and B, bolted to the cylinder heads. No exhaust valves are required, the products of combustion being allowed to escape through the ports, C and D, cast in the middle of the cylinder and connected to the exhaust pipes. These ports are alternately covered and uncovered by the power piston itself, and, for this purpose, the piston is made very long and is packed at each end by self-closing piston rings.

The charge is admitted through two double-acting auxiliary pumps, E and F, one for gas and the other for air. The proportions of these pumps are such that their combined action always secures a mixture, having the proper proportions of gas and air for perfect combustion, and introduces the same into the working cylinder. The delivery branches of the pumps are divided and so arranged that the crank ends of both pumps discharge into the crank end of the power cylinder, and the head ends into the head end of the power cylinder. These pumps compress the gas and air to about nine pounds per square inch.

Referring to *Fig.* 95, it will be noted, that the piston is at the outer dead point, and that the exhaust ports are uncovered towards the head end of the cylinder. In operation, the instant the piston begins to uncover these ports, the pressure of the products of combustion of the previous charge drops rapidly to that of the atmosphere. and when this occurs, the inlet valve opens, and a fresh charge is admitted by the pumps. The valve gear of the pumps is so designed, that, at first, air only is admitted to the cylinder, thus separating the products of combustion from the succeeding charge of gas and air.

The entering charge is formed only at the inlet valve, and is not kept stored up, outside the power cylinder, as is more or less customary in gas engine practice. By the peculiar design of the admission device, the air, first admitted, is prevented

from mixing with the products of combustion remaining in the cylinder, or with the succeeding charge, and in a similar manner, suitable arrangements effectively prevent the loss of any

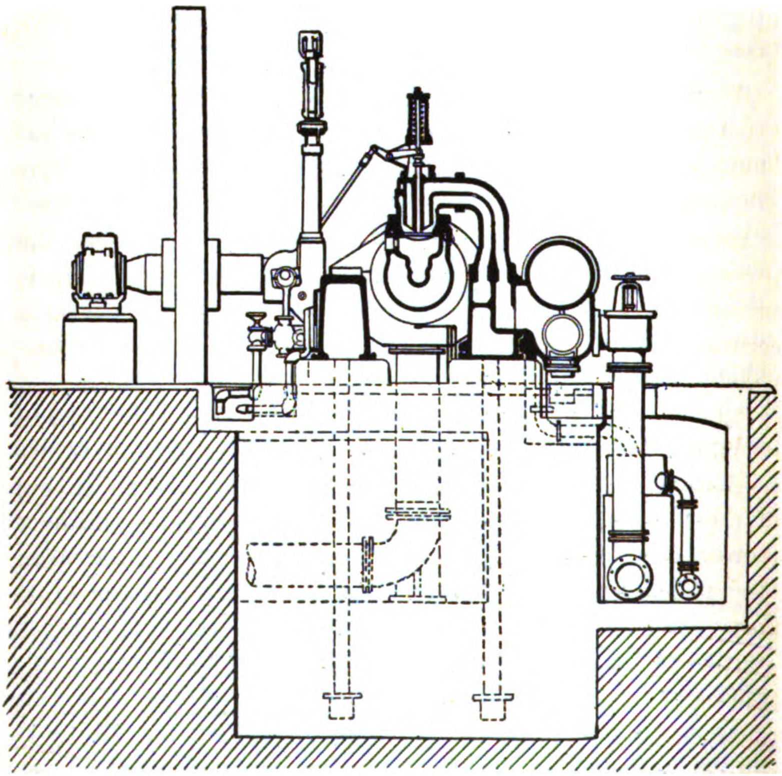


FIG. 96.—KOERTING ENGINE.
Cross Section through Suction Valve.
(Paragraph 215)

portion of the fuel charge through the exhaust ports, which remain open during this period.

Shortly after the exhaust ports are again covered by the receding piston, the air and gas pump pistons also arrive at their dead point position, and the supply of mixture is interrupted. The inlet valve now closes, and the charge is compressed in the cylinder, in the usual manner, until ignition takes place at the dead point of the stroke.

At the next movement of the power piston, the ignited charge expands, exerting pressure until the piston uncovers the exhaust ports and allows the blowing out of the consumed charge. The same operation takes place at the opposite end of the piston.

In order to secure the separating layer of air between the products of combustion and the fresh charge, the gas pump is so constructed that no gas is delivered until it has passed a certain point in its compression stroke. The pump is provided with piston valves operated by a valve gear so arranged that its maximum capacity cannot exceed 50 to 60 per cent. of its total displacement. For, after the pump has completed its suction stroke, the gas suction port is left open during a part of the compression stroke, so that the gas can return without increasing in pressure until the suction port is closed, when the gas is compressed and passed out through the compression port.

The development of power is regulated as follows: When the load on the engine is reduced, the gas pump furnishes gas at a correspondingly later period, thus discharging a reduced quantity of gas into the power cylinder. This is effected either by the valve gear of the pump under the control of the governor, or by means of a by-pass located between each pump-end and its respective compression channel leading to the inlet valve on the power cylinder. The throttling device located in this bypass is also controlled by the governor.

It will be noted that the engine operates with a variable amount of mixture, and that, correspondingly, more or less air is at first discharged into the power cylinder. This air lies against the piston, while the combustible mixture remains at the ends of the cylinder near the inlet valves and igniters. The peculiar shape of the cylinder ends prevents the mingling of this layer of air with the succeeding fresh charge.

Ignition is effected by means of two spark coils, located at each end of the power cylinder, and operated by a separate shaft driven by spur gears from the cam shaft. The gear on the igniter shaft is not fast, but is connected to a sleeve having a feather set spirally around the shaft, so that, by a sliding movement of the wheel, the igniter shaft may be set behind or in advance of the cam shaft. In this manner, the time of ignition can be changed to suit the kind of fuel being used, while the engine is in operation.

Starting is effected by means of compressed air. A piston valve is provided for admitting the compressed air to both ends of the cylinder; this valve is operated from the cam shaft by an eccentric which can be thrown in and out of gear like a clutch. Filling the cylinder twice with air is usually sufficient for starting, after which the engine will continue to run on its own fuel.

The power cylinder and the piston are water-cooled. In the case of the piston, the water enters by a tube carried through the cross head pin and hollow piston rod, and returns in the same way through the annulus between this tube and the rod. The stuffing boxes in the cylinder head are surrounded by water, and the cylinder walls are cooled throughout, except at the middle, where the exhaust ports are located. The cooling of the charge during compression is increased by means of ribs

cast on the walls of the combustion chamber, the developed area of which is predetermined, by calculation, to suit the degree of compression which the ignition temperature of the gas will permit.

These engines are built by the De La Vergne Machine Co., of New York.

216. **Double-Piston Two-Cycle Engines.** In order to avoid many difficulties, such as premature explosions in the crank-case, insufficient scavenging of the products of combustion, etc., incidental to the operation of two-cycle engines on the general principle described in paragraph 61, numerous attempts have been made by various inventors to produce two-cycle engines operating with two pistons in a single power cylinder. This means that the cylinder is an open-ended tube, the explosions taking place *between* the two pistons, forcing them apart.

The first important engine of this type appears to be the Atkinson differential engine, of English make, and exhibited for the first time at the Inventions Exhibition in London, during 1885.

It is well to understand in this connection, that up to the present time, engines of this type have not proved very satisfactory practically, and that the brief descriptions of a few examples, given in this paragraph, are introduced merely for the purpose of showing in a general way the results of efforts in this direction.

217. **The Atkinson Differential Engine.** *Fig.* 97, gives a general view of the engine in elevation, and the four diagrams of Fig. 98, show the positions of the two pistons at different points of the cycle.

It will be noted that only one cylinder is used for all purposes of the cycle. Two trunk pistons work in the opposite ends of this cylinder, and are connected by an ingenious system of levers and short connecting rods to the crank shaft, the short rods causing the necessary action.

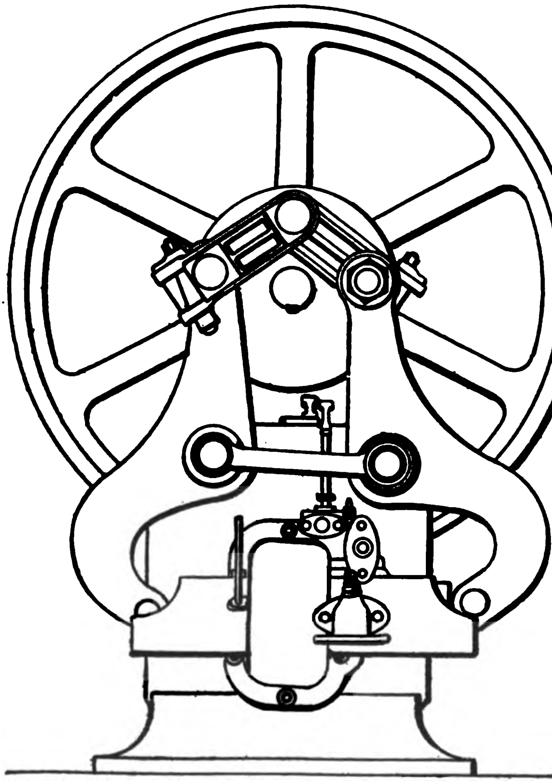


FIG. 97.—ATKINSON DIFFERENTIAL ENGINE.
Side Elevation. (Paragraph 217)

In the first position shown in *Fig.* 98, the pistons occupy one extreme of their stroke and are just beginning to separate. The charge is now admitted between them through an automatic

lift valve. In the second position, the admission of the charge has been completed, and the further movement of the pistons is about to close the ports leading to the admission and exhaust valves. The charge is now subjected to compression, and when

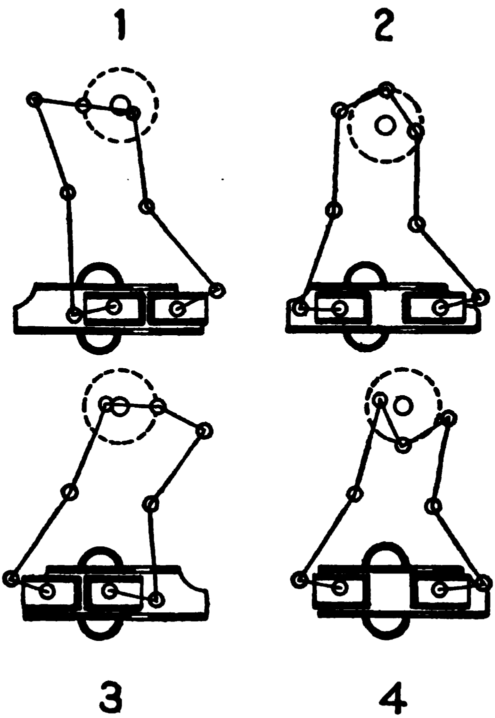


Fig. 98.—Atkinson Differential Engine.
Position of Piston at different points in the Cycle.
(Paragraph 217)

this process is completed in the third position, it is ignited, the resulting explosion causing the pistons to separate rapidly, and uncover the exhaust port and discharge the products of combustion in the fourth position.

By this arrangement, the operations of admission, compression, ignition, expansion, and expulsion are performed in the single cylinder during one revolution of the crank shaft. Only two automatic valves are employed, and these are never exposed to the pressure of the explosion, the pistons themselves acting as valves in certain parts of the cycle so as to uncover the exhaust and admission ports when required, and to uncover the ignition port at the proper time.

218. **The Riker,** (*U. S. Patent No. 349,858—1886.*) The specifications, under this patent describe an engine consisting of a single cylinder open at one end, and having two pistons working therein in opposite directions as follows:

Referring to *Fig.* 99, and assuming the engine to be at rest with the working parts in the position shown in the drawing. The pistons are respectively at the upper and lower limits of their movement, the lower exhaust port, A, is closed, while the corresponding supply port, B, has just opened. To start the engine the crank shaft is revolved by hand, and as piston, C, begins to ascend, a partial vacuum is created in the lower part of the cylinder, the suction drawing in a charge of air and gas through the port, B, into the chamber, D, the cock, E, being so turned that the lower gas port is opened. As piston, C, continues to ascend, the accompanying ascent of the rod, F, closes the port, B, and turns the cock, E, so as to shut off the supply of gas. When port, G, comes opposite the burner, H, an explosion occurs. The pistons now approach each other, and when they reach the limits of their stroke in this direction, the exhaust port, J, which up to this time has been open is closed by the valve, K. The same motion of the rod, L, also opens the lower exhaust port, A, so that as the piston, C, descends, the

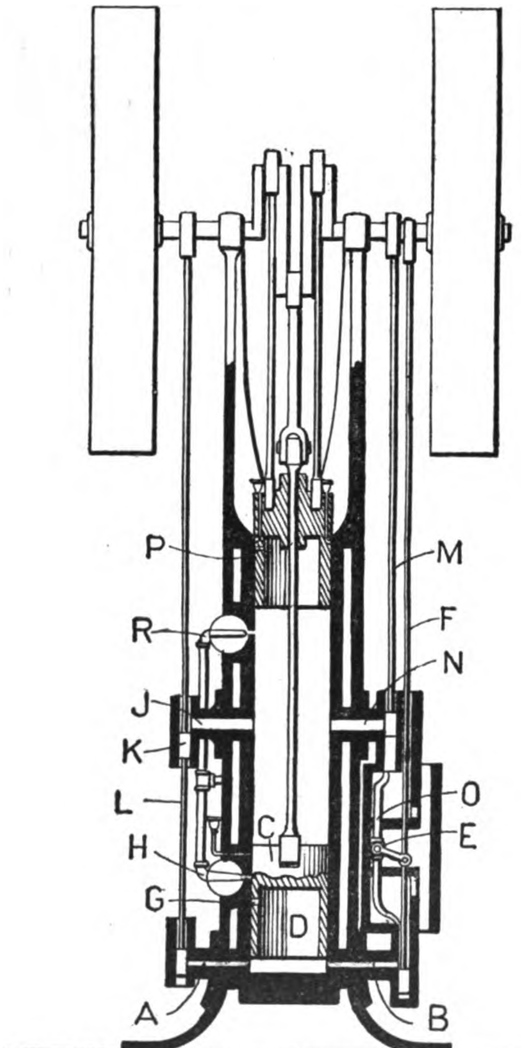


FIG. 99.—RIKER DOUBLE-PISTON TWO-CYCLE ENGINE.
(Paragraph 218)

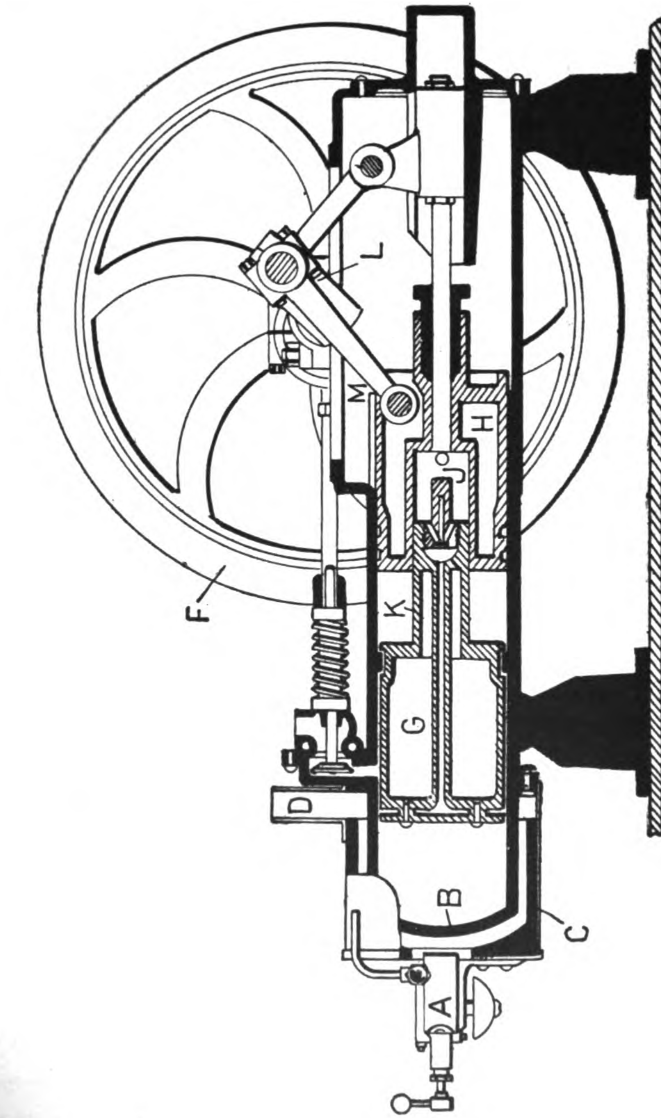


FIG. 100.—ANDERSON-ERICKSON-WICKSTROM DOUBLE-PISTON TWO-CYCLE ENGINE. (Paragraph 219)

products of combustion of the first charge are driven out of the cylinder. By this time, the rod, M, has opened the supply port, N, and rod, F, has reached the top of its stroke, closing supply port, B, and turning the three-way cock, E, so as to open the upper orifice of the gas pipe, O. This is the position of the parts when the pistons begin to separate. A charge then enters through the port, N, and is ignited when the ignition port, P, comes opposite the gas burner, R. The resulting explosion drives the pistons apart.

219. The Anderson-Erickson-Wickstrom. (*U. S. Patent No. 714,356—1902.*) The specifications of this patent describe an engine capable of being operated either by heated air, or by an explosive mixture of air and gas. It employs two pistons working in a single cylinder, and operates as an internal combustion motor as follows:

Referring to *Fig.* 100, the burner, A, having been heated in any ordinary manner to a temperature sufficiently high to vaporize the fuel oil used, its valve is opened and the burner ignited. The flame thus obtained is directed upon the inner end of the heater, B, and being deflected around its sides in the space between the heater and the refractory lining, C, discharges the products of combustion into the atmosphere through the vessel, D. When the heater has thus attained the required temperature, the fuel admission valve, E, is opened and the fly wheel, F, is given an initial revolution, whereby the transfer piston, G, and the power piston, H, will recede from each other, drawing air into the space formed between them, and fuel gas or vapor into the cylinder, J, behind the trunk piston, K. The pistons having, during their opposite or separating movement, thus drawn in the required amount of air and vapor, the trans-

fer piston, on account of the manner of its connection to the crank, L, will remain substantially stationary at the end of its instroke, while the power piston, on account of the manner in which it is connected to the crank, L, will travel rapidly inward toward and behind the transfer piston, thereby compressing the charge in the comparatively cool parts of the cylinder. At about the completion of the instroke of the power piston, the transfer piston commences its outstroke, and by traveling towards the power piston transfers the charge to the combustion chamber within the heater, B, where it is automatically ignited by direct contact with the heated walls, expands and drives the pistons outward on the power stroke. When the pistons have almost completed their outstroke, the exhaust valve, M, is opened by suitable actuating devices and discharges the products of combustion into the atmosphere.

The engine having thus received its power stroke, the momentum of the fly wheel causes the next intake, compression and transfer of the charge, followed by the second impulse, so that one power stroke is obtained during each revolution of the crank shaft.

220. The Clifton, (*U. S. Patent No. 792,119—1905.*) This patent describes an engine of the vertical type, having one cylinder with two pistons working therein. The cylinder is provided with an inlet valve at one end and an exhaust port at the other, and the compression chamber is partly formed by the pistons themselves. The charge is drawn in on the inlet valve side of the piston and compressed into the compression chamber from which it is transferred to the other end of the cylinder and there ignited.

Referring to *Figs.* 101, 102, and 103, which are sectional views of the cylinder showing the pistons in different positions, the action of the engine may be described as follows:

On the down stroke, the products of combustion are expelled from the lower or ignition side of the piston, B, through the exhaust valve casing, J, while at the same time a fresh charge is drawn into the cylinder on the compression side of the piston, A, through the suction valve casing, K, as shown in *Fig.* 101.

On the upstroke, the charge drawn is above the piston, A, is compressed into the space between the two pistons, the fluid pressure overcoming the resistance of the spring, E, and forcing the piston, B, away from the piston, A, as shown in *Fig.* 103, the charge being trapped in the space between them, which thus forms the compression chamber.

At the end of every downstroke, the charge compressed between the pistons is delivered through the ports, G, into the cylinder space below the piston, B. As the charge escapes, the piston, B, moves up to the piston, A, so that they are again in touch before the charge is ignited as shown in *Fig.* 102, and both commence their upstroke together. Near the end of the upstroke, the compression on the charge drawn in at K, will overcome that of the spent charge, and while the piston, A, completes its upstroke, allowing the fresh charge to pass through the passages, C, in the piston A, the piston, B, will be gradually stopped by the pressure of the charge passing through the piston, A. When the piston, A, reaches the top of its stroke, practically all of the gas is trapped between the pistons and carried down by them to the lower part of the cylinder, while at the same time another charge of gas is being drawn in at K. Thus, on the following upstroke, explosion and compression occur simultaneously on different sides of the pistons.

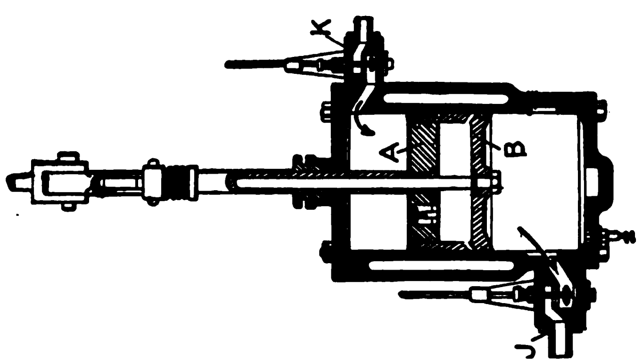


FIG. 101.

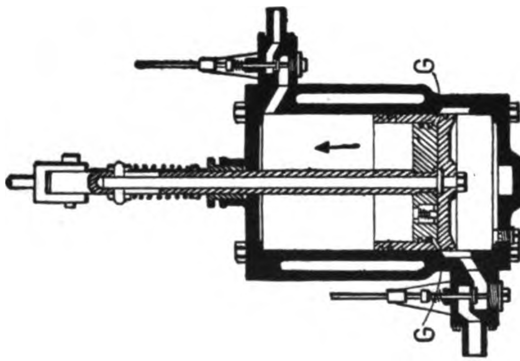


FIG. 102.

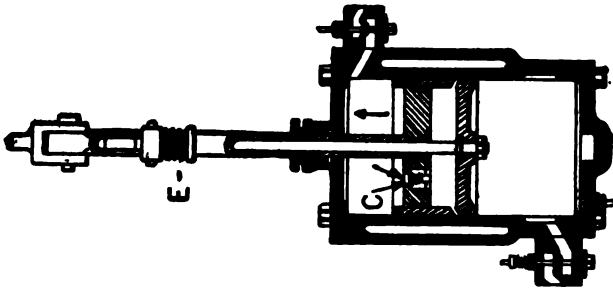


FIG. 103.

CLIFTON DOUBLE-PISTON TWO-CYCLE ENGINE.
Sectional View of Pistons at different points of the Cycle.
(Paragraph 220)

The advantages of a two-cycle motor over the four-cycle are due to the greater frequency of its impulses, and may be stated as: 1, more uniform and sustained rotating effort or torque, lending itself to more accurate governing and greater flexibility in meeting a varying demand; 2, lessened weight for equal power; 3, uniform compression, with consequent economy, as no more exhaust can go out than charge come in, thus keeping the same total quantity of charge in the cylinder, the action of the governor tending to vary only the proportions of gas to the total charge.

The chief disability, under which the ordinary classes of two-cycle motors appear to have labored, is a certain lack of positiveness in functioning as compared with the rival type. The various engines illustrated and described in these paragraphs have been devised with a view to removal of this disability, and, in their efforts to attain this end, the inventors have produced machines offering a marked contrast to the extremely simple two-cycle marine engines described in Chapter XXI.

It is, however, conceded by many authorities that a certain amount of complexity is necessary to give absolutely positive action to the two-cycle motor, either by the addition of inlet and gas valves or by auxiliary charging and scavenging cylinders. On the other hand, the exhaust valve, a chief source of trouble in internal combustion engines, may be dispensed with by adopting the two-cycle mode of operation, and the trend of modern practice seems to favor this view of the question.

For further information on the working principles of two-cycle engines—see paragraph 244.

CHAPTER XIX.

FOREIGN ENGINES.

221. German Engines. It is well recognized that up to the years 1904 and 1905, the German gas engine makers led all others in the development of high powered internal combustion engines. Since then, however, this supremacy has been successfully contested by the American makers, but it will be noticed, that with one or two exceptions, such as the Westinghouse double acting engine, and the Sargent, the American product is of foreign origin.

The Nürnberg built by the Allis-Chalmers Co., The Cockerill made by the Wellman-Seaver-Morgan Co., and the Koerting of the De La Vergne Refrigerating Machine Co., are of German design; while the American Crossley is the American duplicate of the English Otto-Crossley. All of these are fully described in Chapter XVII, together with the Westinghouse and Sargent engines.

Of the other larger German engines, the most important are the Oechelhauser, built by the firm of A. Borsig, Tegel, near Berlin, and the Duetz, built by Gasmotorenfabrik Duetz, near Cologne.

222. The Oechelhauser. This engine is of the two-cycle, single-cylinder type, and one of the simplest among the numerous forms of large gas engines.

As shown by *Fig.* 104, two pistons, A and B, work in opposite directions in a long cylinder, C, which is open at both ends,

and provided with ports, D, E, and F, which, being uncovered consecutively by the pistons during their outward stroke, effect the distribution. The piston, A, first uncovers the ports, D, through which exhaust the compressed products of combustion, and, as soon as the pressure of the latter has fallen to that of the atmosphere, the piston, B, uncovers the ports, E, admitting pure air into the cylinder which sweeps out the products of combustion still remaining therein. Immediately thereafter, the piston, B, uncovers the ports, F, and admits a fresh supply of gas into the cylinder, where it mixes with the air which continues to enter at the ports, E, together forming the explosive mixture for the fresh charge. This charge is compressed by the

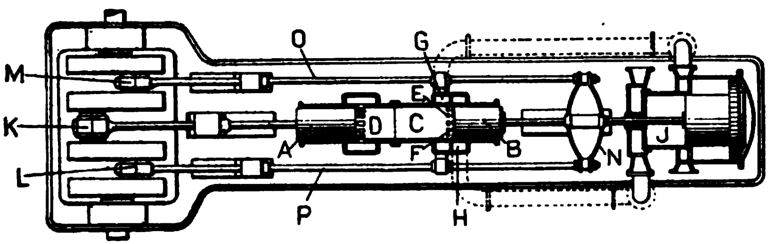


FIG. 104.—OECHELHAUSER TWO-CYCLE ENGINE.
Sectional Plan. (Paragraph 222)

return stroke and ignited by means of two magneto igniters when the pistons are in the middle of the cylinder, so that the force of the resulting explosion drives them apart, giving a power stroke for every revolution of the crank shaft.

During the compression and power strokes, the charging spaces, G, and H, the former for air and the latter for gas, are refilled by means of a pump, J, located behind the cylinder, so that a fresh charge under a low pressure, of about 4 to 6 pounds per square inch, is always held in readiness to enter the cylinder at the beginning of the outward stroke of the pistons.

The construction of the engine is such, that while air can enter the charging space for gas, gas cannot enter the charging space for air, thus preventing the gas from passing out through the exhaust ports, and, furthermore, the dimensions of the cylinder are such that only 70 per cent. of its full capacity is required to be filled with the charge for the development of the maximum power of the engine.

The piston, A, acts directly on the crank pin, K, of the three-throw crank shaft, and the piston, B, acts upon the two outside crank pins, L and M, by means of the cross-tail, N, and the connecting rods, O and Γ.

Governing is effected by regulating the quantity of gas admitted to the cylinder, so that the amount of gas in the charge is always proportional to the power demand at any moment.

The principal advantages of the engine are derived from the following conditions:

1. The reduced cylinder diameter diminishes the intensity of the forces acting on the driving parts.

2. The movement of the pistons in opposite directions enables the exact balancing of the reciprocating parts.

3. The transmission of the whole power developed by the engine through its moving parts alone, prevents the application of horizontal strains to the frame, and obviates the necessity for extra heavy foundations and strong holding-down bolts.

4. The absence of valves insures safe action and great durability.

The only valve employed is the small one used for starting the engine with compressed air. A compressor, coupled to an electric or gas motor, furnishes compressed air, under a pressure of about 300 pounds per square inch, to a vessel communi-

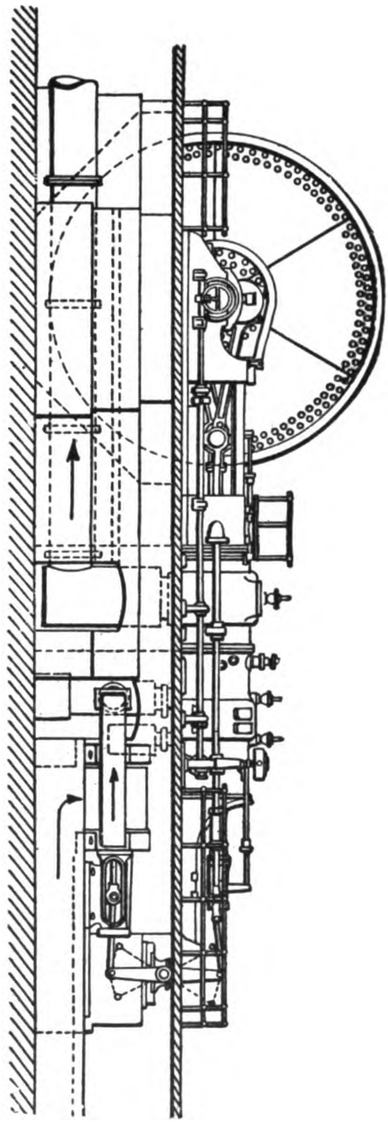


FIG. 105.—OECHELHAUSER ENGINE.
Side Elevation.
(Paragraph 228)

cating with the engine cylinder, through this valve which is controlled by the engine itself. After the first ignition the valve is closed, and the gear disengaged by the operator.

The engine is built in both the single and double-cylinder types, the former ranging in size from 250 to 1,500 brake horse-power, and the latter from 500 to 4,000 brake horse-power. They are capable of sustaining an overload of 10 per cent. above the figures given, when working regularly, and of 20 per cent. temporarily. *Fig.* 105, shows a side elevation of the engine.

223. **The Deutz.** This engine is of the double-acting four-cycle type and is built in sizes up to 6,000 horse-power.

Fig. 106, shows a longitudinal section of the engine, and *Fig.* 107, a vertical cross section through the cylinder and a set of valve chambers.

As shown by *Fig.* 107, the exhaust valves, A, are opened by a cam and link arrangement operated from the secondary or lay shaft, B, and are closed by means of springs. The admission valves are opened in the same way, by means of cams and linkages, but their travel is controlled and varied by the governor, C, through the bell-crank arm, D, carrying the roller, E, which serves as the fulcrum of the lever, F, operated by the cam mechanism.

The position of the roller determines the ratio of the travel of the reach rod, G, and that of the admission valves, and thus regulates the quantity of explosive mixture admitted to the cylinder.

The admission valves are composite, the air valve, H, being of the piston type and controlling the admission of air from the supply pipe in the usual manner. It carries at its upper end

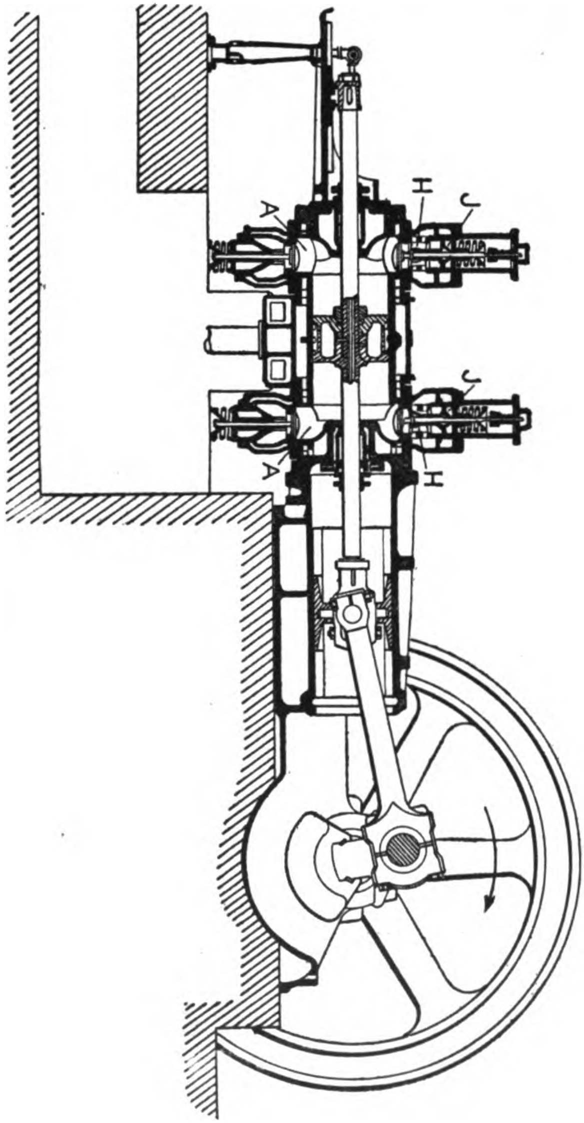


FIG. 106.—DEUTZ DOUBLE-ACTING, FOUR-CYCLE ENGINE.
Longitudinal Section.
(Paragraph 223.)

a poppet valve extension, controlling the admission of gas through the port, J, into the valve chamber, where it is mixed with air and forms the charge. The action of the governor controlling the movement of the valves is so sensitive that the speed fluctuation is not over one-half of one per cent., when the load

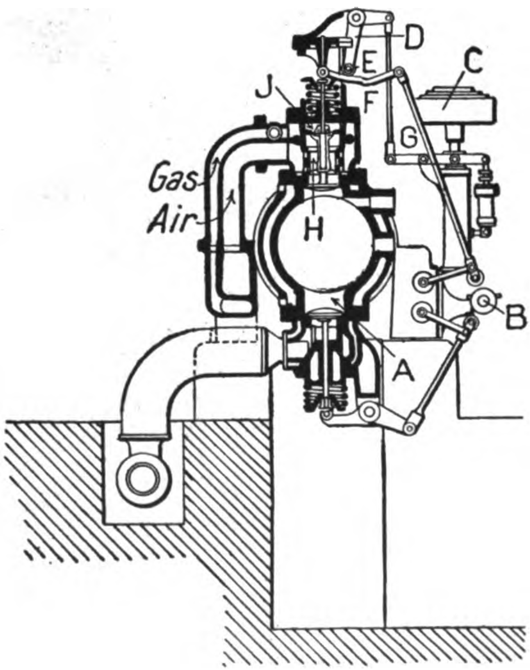


Fig. 107.—Deutz Engine.
Cross-Section through Cylinder and Valve Chambers.
(Paragraph 223)

is suddenly increased or decreased 25 per cent., and the variation in speed between no load and full load does not exceed three-quarters of one per cent.

The double-acting construction necessitates the use of stuffing boxes, but they do not appear to be the source of any trouble whatsoever.

Fig. 106, gives an idea of the general construction. The piston is packed by rings of a special type, and both the piston and piston rod are made hollow, thus providing passages for the circulation of cooling-water.

The arrangements for cooling have been made very carefully and effectively. The cylinder, cylinder head and valve, and the discharging valve and pipe receive cooling-water separately, thus permitting independent regulation of their temperatures. A lever-driven pump is employed to force the cooling-water through the water jackets.

Starting is effected by means of compressed air furnished by an auxiliary apparatus.

224. **French Engines.** Among the more important engines built by the French makers are the *Letombe,* the *Roser-Mazurier,* the *Charon,* the *Gnome,* and the *"Progress"* motor of Lacroix and Company.

225. **The Letombe.** This engine is built in both the single and double-acting types, the latter being of the tandem-cylinder pattern. In the single-cylinder engine built by the same makers and named the *Duplex* motor, the engine is made double-acting by the use of a stuffing box.

In all types, these engines operate on the four-cycle principle, but in the *Duplex* motor the handling of the charge is somewhat modified. Gas and air are first admitted to the back end of the cylinder during the whole of the charging stroke. During the following compression stroke one-half of this charge is transferred through a by-pass to the front end of the cylinder,

and the remainder is compressed and exploded at the end of the stroke. During the compression stroke, the portion of the charge transferred to the front end of the cylinder, amounting to only one-half of the full volume of the cylinder, is necessarily expanded below its normal pressure, but, as the communication to the large connecting passage remains open, the reduction in pressure does not become serious.

The outward power stroke compresses this charge, which is exploded on the return, at the same time exhausting the products of combustion of the charge already exploded in the rear end of the cylinder. Thus, at each revolution, there is both a power and a compression stroke. The volume of the charge used is the same as in the case of a single-acting four-cycle engine, but, as only a half-cylinder full is exploded at a time, and is expanded to the full volume of the cylinder, the ratio of expansion is greater and gives a higher mean effective pressure with the same amount or volume of gas.

It resembles a steam engine, having cross head, guides, etc., and a stuffing box on the crank end of the cylinder. The introduction of the stuffing box does not conform to customary gas-engine practice, but the cylinder head is so thoroughly water-jacketed that no difficulty is experienced with ordinary packing and lubrication.

226. The Roser-Mazurier Compound Gas Engine. This engine possesses some original features not usually met with in ordinary gas engines.

As shown by *Fig.* 108, it is of the vertical multi-cylinder type, and consists of three cylinders arranged side by side. The charge is admitted alternately to the two outside cylinders through the valves, A and B, and exploded in the chambers,

C and D, formed by recesses in the pistons. Ignition is effected by means of sparks from a Ruhmkorff coil. The two outside pistons have their cranks in the same line and therefore move together, but the crank of the piston of the larger central cylinder is set opposite the other two. While one of the outside pistons makes its power stroke the other draws in its

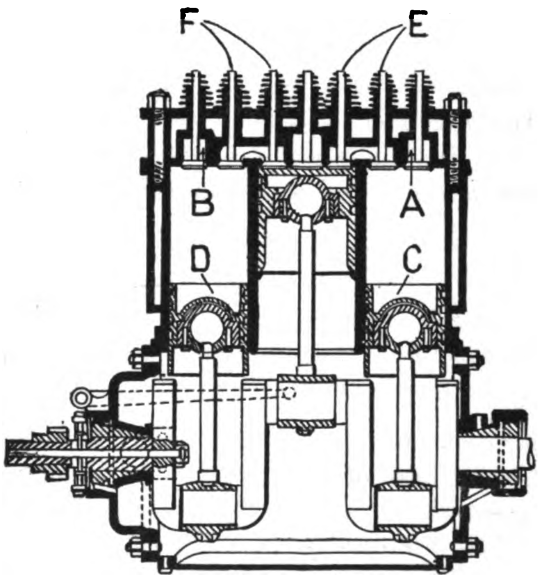


FIG. 108.—ROSER-MAZURIER COMPOUND GAS ENGINE.
Vertical Cross-Section through Cylinder and Valve Chambers.
(Paragraph 226)

charge, so that on every outstroke of the engine either one or the other of the outside pistons makes a power stroke.

At the end of the power stroke of each of the outside pistons, the products of combustion in their respective cylinders are passed through the valves, E and F, into the central cylinder, where their residual pressure becomes expanded to a little above

that of the atmosphere, thus driving the central piston on its power stroke. As the power stroke of this piston occurs during the inward stroke of the outside pistons, the combined action of these three pistons gives the engine two working or power strokes for every revolution of the crank shaft. The cycle of the engine is a unique combination of the essential principles of the four-cycle, two-cycle, and compound methods of operation.

As no combustion takes place in the central cylinder, the water jacket is omitted in this case, the space thus gained being applied to obtain a larger bore with an outer diameter the same as those of the outside water-jacketed cylinders.

The weight of the central piston and reciprocating parts is made equal to the combined weight of the two outside pistons and their reciprocating parts, and as the central mass moves in a direction opposite to that of the two other weights, their momentum and inertia effects are completely balanced.

The shaft center is not in the same place as the cylinder centers, so that the force of the explosions acts upon a lever arm of some magnitude at the very beginning of the power stroke. The idea of this arrangement is that the more rapid movement of the power stroke thus obtained allows less time for the cooling of the expanding gases.

Governing is effected through regulating the amount of gas admitted by a butterfly valve controlled by a centrifugal shaft governor, so that the shaft receives an impulse at each power stroke regardless of the load.

This engine is built in small powers only, and is designed to operate on either gas, or any of the lighter petroleum products.

227. The Charon. In this engine a portion of the charge, drawn into the cylinder on the charging stroke, is allowed to escape on the compression stroke into a receiver; the remainder, which is always maintained proportional to the load on the engine by the action of the governor, is compressed and exploded at the end of the stroke, thus giving a greater range of expansion.

This is accomplished by keeping the admission valve open during part of the compression stroke, as determined by the action of the governor.

228. The Gnome. This engine is of the inclosed crank-chamber type similar to the Westinghouse. The moving parts run in a bath of oil, and the engine is designed to run at high velocity. It can be operated with either gas or oil, and works on the four-cycle principle.

229. The "Progress" Motor. This engine is of the vertical single-acting, four-cycle type, and is designed to operate with gas, gasoline, acetylene, petroleum, naphtha, or alcohol, and requires but slight modifications of the accessory devices to adapt it to each of the different kinds of fuel enumerated.

Fig. 109, shows a vertical section through the crank shaft and cylinder. The suction caused by the descent of the piston draws in air through the valve, A, and, at the same time, the vapor derived from the fuel.

A few drops at a time of the operating medium are forced by a pump, operated by a cam, B, into the vaporizer, located at the top of the cylinder, this being kept at a dull red heat by the temperature of the explosions. On the upward stroke the charge is compressed and ignited by contact with the hot vaporizer.

Governing is effected by means of the centrifugal governor in the fly wheel, which moves the ring, B, and the latching de-

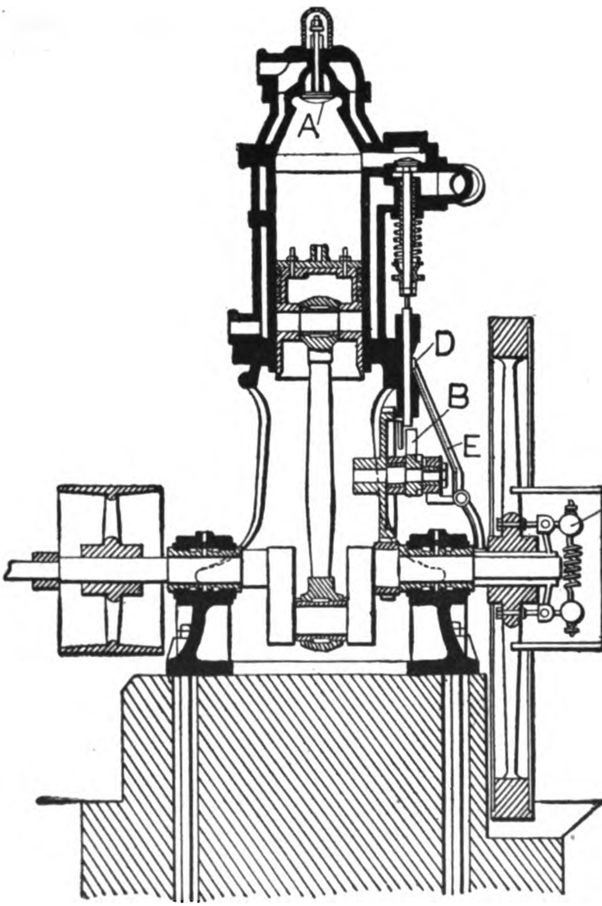


FIG. 109.—LACROIX "PROGRESS" MOTOR.
Vertical Section. (Paragraph 229)

vice, D, through the lever, E. The latching device throws the pump out of action, suspending the injection of oil into the

vaporizer until it is again required to maintain the speed of the engine. The quantity of oil injected by the pump is constant, and the proper mixture for perfect combustion is obtained by the regulated action of the air valve.

The inception and development of the gasoline automobile has been principally due to French inventors and engineers, consequently many of the details of those types of internal combustion motors, suitable for such vehicles, are of French origin. On the other hand, apart from the alcohol motors referred to elsewhere, German engineers have excelled more in the production of large stationary engines using lean gases.

With this trend of development the French have constructed motor boats of exceedingly high speed; one, the *Panhard-Tellier* having attained a speed of 37.3 statute miles an hour. Working in the same direction, other firms have built motors of extremely light weight for aerial navigation, one six-cylinder four-cycle engine by Pelterie developing 35 horse-power with a weight of slightly less than 100 pounds. An eminent builder, Georges Richard-Brasier, has greatly simplified the gasoline motor by fitting a pump feed for the fuel, thus doing away with the carburetter and ensuring equal regulation of the multi-cylinder types of engine now in use.

CHAPTER XX.

OIL ENGINES.

230. Working Principles of Oil Engines. The general principle of operation of oil engines is the same as that of gas engines—the fuel is introduced into the cylinder, is ignited and consumed therein, and the energy thus developed is utilized to drive the piston. Engines using gasoline differ but slightly from gas engines, but those using kerosene or crude oils are often built on very different lines.

231. Gasoline Engines. These machines usually differ from gas engines only in the use of a carburetter and a small pump for forcing the gasoline into it. These devices may be added, however, to any gas engine and thus enable it to use gasoline efficiently.

In the general operation of gasoline engines, it is also possible to use this fuel by injecting it directly into the cylinder, in the form of a liquid, without first passing it through a carburetter, but this method does not give so high a fuel efficiency because the gasoline becomes imperfectly mixed with air, resulting in much slower, and therefore less complete, combustion.

232. Carburetters. A carburetter is a vessel in which the gasoline is vaporized and mixed with air, prior to its introduction into the power cylinder, and the highest fuel efficiency is obtained from the use of such devices as those which will completely saturate the air with gasoline vapor.

These devices may be grouped into three general classes according to their mechanical arrangement and method of operation, as follows:

1. Surface carburetters, in which the air is passed over the

surface of a body of liquid hydrocarbon, or circulated around a gauze, wicking, or metallic surface saturated with such a liquid.

2. Filtering carburetters, in which the air is forced by suction through a body of liquid hydrocarbon, so that it becomes impregnated with some of the substance of the liquid.

3. Float feed carburetters or sprayers, in which the liquid hydrocarbon is discharged, as a fine spray, through a minute nozzle or some form of atomizer, and thus mixed with a passing column of air. See paragraph 249.

233. **The Daimler Carburetter.** The general construction of this device is shown by *Fig.* 110, and its operation may be briefly described as follows:

The gasoline is admitted to the tank, A, through the pipe, B. A float, C, supports a conical chamber, D, in which the level of the gasoline is maintained constant, regardless of variations of the level of the gasoline in the tank. The entering air passes through a jacket around the exhaust pipe of the engine and is thereby heated before reaching the carburetter. Passing through the passage, E, the heated air vaporizes a certain amount of the gasoline in the chamber, D, and then the mixture thus formed passes the baffle plates, F and G, to the admission valve of the engine through the pipe, H. Usually, the admission valve is constructed so as to allow the entrance of fresh air, which mixes with the gasoline-saturated air from the carburetter in the same manner as air and gas are mixed before their introduction into the combustion chamber of a gas engine, but, in the present case, the gasoline vapor being already well mixed with air, the quantity of fresh air admitted at the valve is relatively smaller.

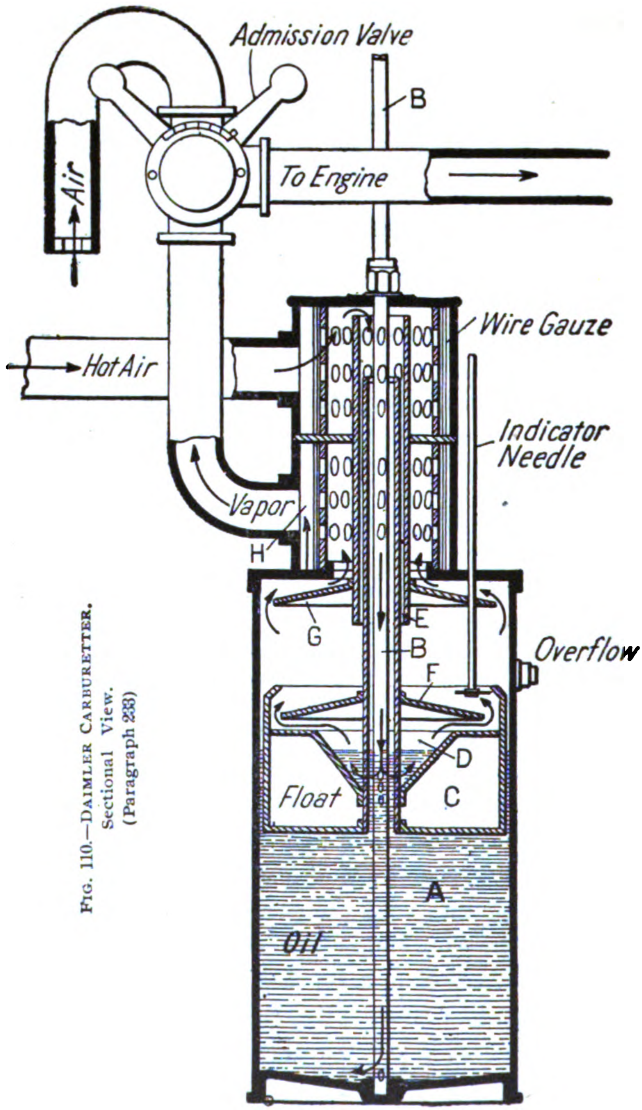


FIG. 110.—DAIMLER CARBURETTER.
Sectional View.
(Paragraph 233)

As a general rule, carburetters are not quite as complex as this arrangement. Any device, by which gasoline can be vaporized and the air thoroughly saturated with its vapor, will give economical fuel consumption. The simple form shown in *Fig.* 111, operates as follows:

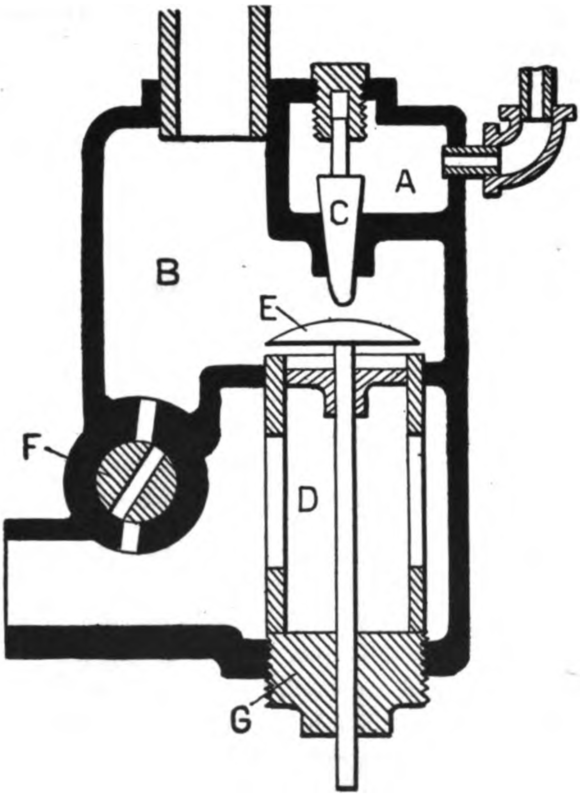


FIG. 111.—SIMPLE FORM of CARBURETTER.
(Paragraph 283.)

From the gasoline chamber, A, the oil is admitted to the mixing chamber, B, through the valve, C, which has a very slight

taper. The valve rod of the engine lifts the valve stem, D, of the valve, E, thus admitting air to the mixing chamber and at the same time opening the valve, C, which delivers gasoline to the mushroom top of the valve, E. The entering air is thus caused to pass through the gasoline which trickles from the rim of the mushroom top of the valve, E, and becomes charged with a portion of its substance. A plug-cock, F, is provided to permit of the dilution of the mixture by an additional quantity of air in the chamber, B. The cage, G, of the valve, D, is adjustable in the casing, and permits of the regulation of the interval of time between the opening of the valves, C and E, so as to produce the best results.

234. **Kerosene Oil Engines.** A gas engine fitted with a carburetter or vaporizer can use kerosene oil without any difficulty whatever, and a great many kerosene oil engines are essentially gas engines with these devices added. The method of fuel-supply usually employed by them consists in spraying the oil, by means of an atomizer, into a hot chamber in which the spray is readily vaporized and mixed with heated air to form the charge for the engine.

On the other hand, there are engines which are especially constructed for the purpose of using kerosene. Such engines are provided with a reservoir, located at a given height above the power cylinder, from which the oil is fed in liquid form into the air admission chamber at the valve opening into the cylinder. Neither carburetters nor vaporizers are used, and the gravity feed renders the use of an oil pump unnecessary.

Another arrangement, commonly used, consists in the addition to the cylinder, of a separate unjacketed combustion chamber, as shown in *Fig.* 116; into this the oil is sprayed immedi-

ately after the completion of the exhaust stroke at the same time that the oil is vaporized by the hot walls of the combustion chamber. On the return stroke, the air is forced into the combustion chamber, and, mixing with the oil vapor, is compressed with it, being ignited at the end of the stroke.

One of the main difficulties encountered in the use of vaporizers in oil engines is due to the fact, that, the process of vaporization requires the raising of the temperature of the oil vapor and the air with which it is mixed to a temperature ranging from 250° to 300° Fahr., at atmospheric pressure. As a result, the specific gravity of the charge is greatly reduced, so that a given volume contains a lesser number of thermal units than when it is at atmospheric temperature, and furthermore, the consequent higher initial temperature results in a higher compression temperature for a given pressure than that attained in the case of a gas engine. The total result is a higher temperature throughout the cycle and a greater loss of heat through the cylinder walls than is the case when the charge is admitted to the cylinder at atmospheric temperature.

The combined effect of these conditions is the imposition of an early limit to the compression ratio, on account of the increased liability to premature ignition due to the higher compression temperature and the lower ignition temperature of the oil vapor, as compared to those involved in the use of coal gas.

Engines which do not use external vaporizers possess the inherent disadvantages of a higher compression pressure accompanied by a lower explosion pressure than those attained by engines of the vaporizer type. This indicates, that for a given size of cylinder and a given quality of fuel, the mean effective

pressure and consequently the power developed will be considerably lower in the former than in the latter.

The following descriptions of some of the standard types of

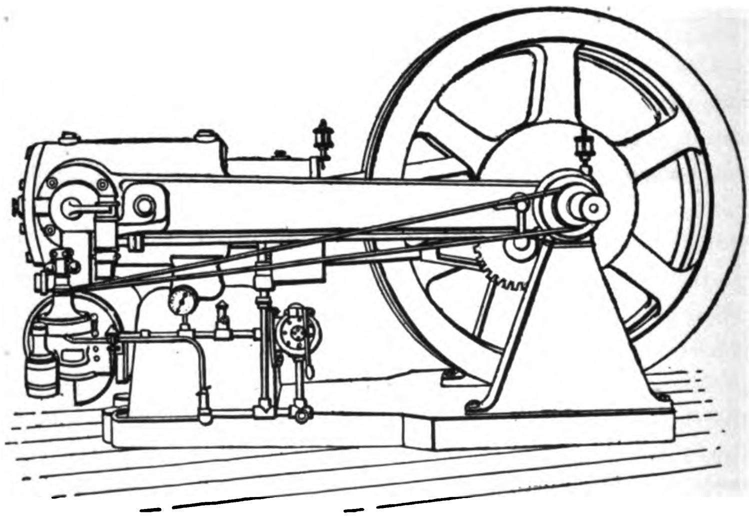


FIG. 112.—PRIESTMAN OIL ENGINE.
(Paragraph 235.)

oil engines will serve to exemplify the various methods and mechanical arrangements adopted by different manufacturers to compensate for the lower efficiencies of oil engines as compared with those of gas engines.

235. The Priestman. This engine is designed to operate by ordinary lamp oil.

Fig. 112, shows a general view of the engine, and *Fig.* 113, a cross section through the cylinder, showing the valves and the mechanism of the vaporizing device.

Referring to *Fig.* 112, it will be noted, that two fly wheels are employed, and that both of them, serving as crank-discs, are mounted between the main bearings instead of being placed at each side of the frame in the usual manner. The engine frame

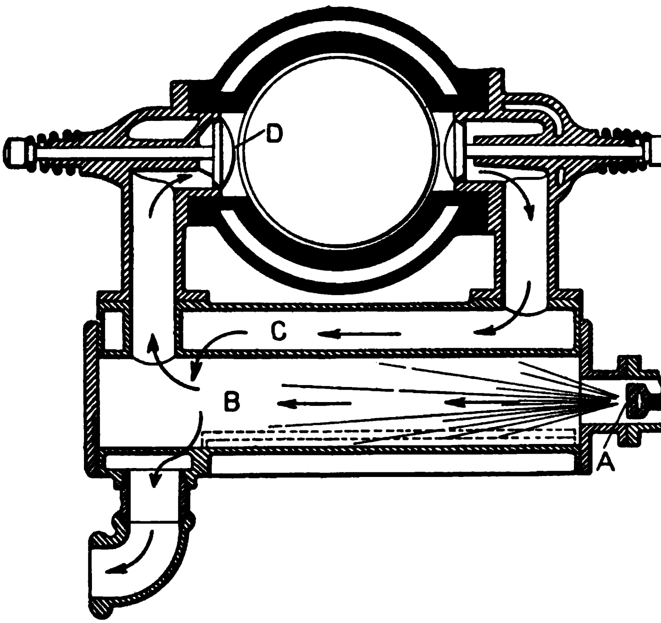


FIG. 113.—PRIESTMAN ENGINE,
Cross-Section through Cylinder, Valve Chambers, and Vaporizer.
(Paragraph 285.)

is bolted to the two forward pedestals supporting the main bearings, and the cylinder rests on the rear pedestal on a ball and socket bearing which is capable of free movement, thus tending to prevent all strains due to expansion and contraction.

The oil reservoir consists of a separate tank which is connected to the engine by three pipes, two of which lead to the up-

per part of the tank, where sufficient space is always maintained above the oil-level for compressed air. An air pressure of five or six pounds is maintained by the pump, located above and in front of the rear pedestal, which is driven by an eccentric from the cam shaft. The oil is lifted to the engine under a running air pressure ranging from 5 to 15 pounds per square inch, according to the size of the engine. The device used for this purpose is shown in *Fig.* 113. A jet of air issuing at a minute nozzle or atomizer, A, converts the oil into a fine spray and injects it into the mixing chamber, B, where it is mixed with free air and heated by the exhaust gases passing through the annular space, C, which constitutes the heater.

Before starting, it is necessary to heat the mixing chamber, with lamps provided for that purpose, in order to prevent the oil spray from condensing on the cold walls, but after the engine is once started, the heat furnished by the exhaust gases is sufficient for this purpose. All engines except those of the smallest size are equipped with self-starters, which are operated by compressed air supplied by a hand pump furnished with the engine, or from a special air tank in which the compressed air has been previously stored by the automatic pump.

The ignition is electric, the jump-spark being used, and the governing is effected by the throttling method, the governor lowering a spindle into the oil pipe and thus reducing the quantity of oil admitted to the atomizer, while at the same time it reduces the quantity of free air admitted to the engine, through a separate valve, for burning the oil. The inlet valve, D, opens under the external pressure of the atmosphere.

No separate device is employed for lubricating the cylinder, as a portion of the oil spray, used as fuel, coats the cylinder walls and furnishes all the oil necessary for proper lubrication.

236. **The Meitz and Weiss.** This engine is of comparatively simple construction, operating on the two-cycle principle; and has no igniting apparatus to require attention and cleaning.

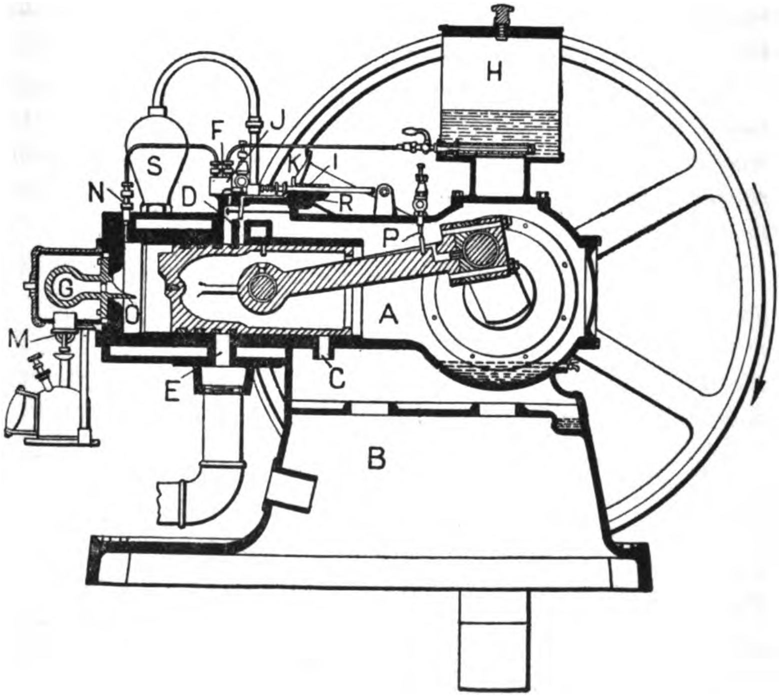


FIG. 114.—MEITZ AND WEISS OIL ENGINE.
Longitudinal Section.
(Paragraph 236.)

Referring to *Fig.* 114, which shows a longitudinal section of the engine, its operation may be briefly explained as follows:

Air is drawn into the closed crank chamber, A, from the interior of the base, B, through the port, C, in the lower part of the cylinder. On the outstroke of the piston, this air is com-

pressed, and the opening of a port, D, by the piston, allows the air, together with the steam generated in the water jacket, to pass into the combustion space of the cylinder. At the same time, the exhaust port, E, having been overrun, and thus opened by the piston, discharges the products of combustion of the previous charge into the exhaust pipe.

The fuel is injected into the cylinder by the pump, F, and mixes with the air and steam previously admitted from the crank chamber, so that on the instroke, or compression stroke proper of the piston, the charge is automatically ignited by contact with the heated walls of the igniter ball, G.

Oil storage tanks capable of holding more than a barrel are placed underground and the engine provided with a small pump to supply the reservoir, H. In most cases, the suction pipe of the injector pump, F, can be connected directly to the storage tank, or to a small tank placed on the floor or on the engine.

The oil pump is of the single-acting plunger type, the suction and pressure checks being screwed into the pump body. A small lever serves to operate it by hand in starting the engine, and to draw the oil in case the pipes are not completely filled. During continuous running, it is operated by a rocker arm connected to the eccentric through the plunger guide, I. The spring around the plunger, L, forces it back to the short spring stop of the guide.

To stop the engine, the pump lever is pulled back while a pressure is exerted on the small projecting pin, K, at the side to lock the plunger guide out of action.

Ignition is effected by means of a hollow cast iron ball, G, located in the projection attached to the cylinder head. A charge is formed at every revolution of the crank shaft and com-

pressed by the piston into the compression space of the cylinder and the interior of the igniter ball, where it is promptly ignited when the piston reaches the dead point. Before starting, the igniter ball is heated for a few minutes by a small oil burner, M. The oil jet from the injection nozzle, N, strikes the projection, O, extending from the igniter ball and is sprayed, vaporized and mixed with the air and steam in the compression space. The igniter ball is maintained at a dull red heat by the heat of the explosions.

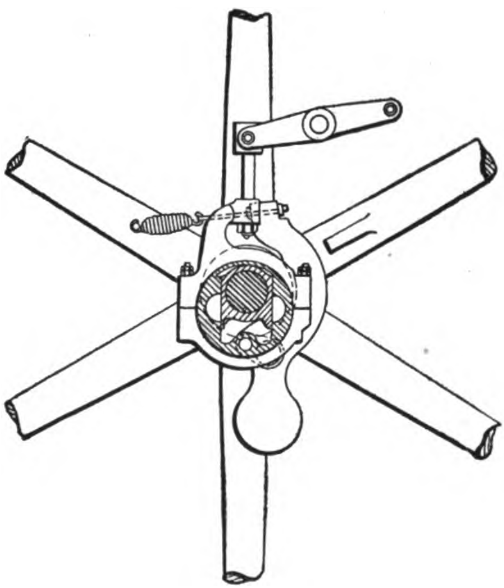


FIG. 115.—MEITZ AND WEISS ENGINE.
Governor.
(Paragraph 236.)

The governor is of the centrifugal type, pivoted to the fly wheel, and is adapted to control the action of the pump plunger. As shown in *Fig.* 115, it consists of a movable eccentric connected to a spring-controlled weight, the centrifugal force of which acts against the spring, shifts the eccentric across the shaft, and results in a shorter stroke of the pump, and consequently the injection of a smaller quantity of oil into the cylinder at each stroke. The movement of the weight is limited by two stops, one on a spoke and the other at the hub of the fly wheel.

The crank and piston are lubricated from an oil well, screwed to the side of the cylinder and connected to adjustable sight feeds. The well being located below the point of feed, the oil is drawn through the sight feeds by suction when the engine is in operation. The crank case sight feed is provided with a projecting tube, P, *Fig.* 114, which feeds the oil directly to the pin in the groove of the connecting rod. The accumulation of oil in the bottom of the crank case furnishes sufficient splash lubrication for the front part of the piston, the main bearing washers, and the piston pin. The cylinder sight-feed is screwed into the pump plate, R, and communicates with the air port of the crank case through a hole drilled across the plate. A tube screwed into the pump plate enters the cylinder oil-hole leading to the top of the piston and the wrist pin.

The cylinder is water-jacketed, and the cooling water supply may be taken directly from the mains or from a tank. The supply pipe is connected to a float box valve, and the water must be under sufficient pressure to run into the jacket of the cylinder. The float keeps the water in the box and that in the water jacket at a constant level, so that the upper gauge cock on the float box shows steam and the lower cock shows water. The

heat of the cylinder generates steam which passes through the dome, S, to the air port communicating with the crank case, and thence, together with the air admitted to the crank case, to the combustion space of the cylinder, where it is mixed with the vaporized oil and forms the charge.

All engines above 30 horse-power are provided with a self-starter consisting of either a hand or belt driven pump and a suitable air tank.

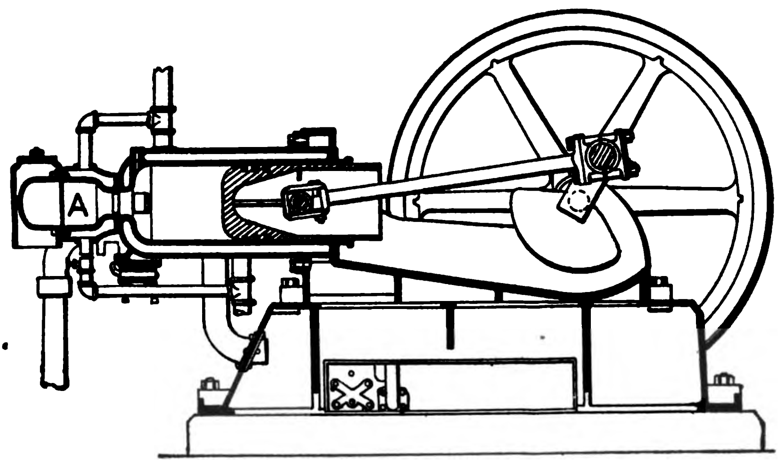


FIG. 116.—HORNSBY-AKROYD OIL ENGINE.
Longitudinal Section.
(Paragraph 237.)

237. **The Hornsby-Akroyd.** This engine operates on the four-cycle principle. The fuel, which may be either kerosene or crude petroleum, is injected and volatilized directly in the bottle-shaped vaporizer. Ignition is effected by the compression of the charge in the combustion chamber, which being partly or entirely without a water jacket, remains at a dull red heat and ignites the charge just as the crank passes the inner dead point.

Fig. 116, shows a longitudinal section of the engine, and *Fig.* 117, a longitudinal section through the valves.

The timing of the ignition is perfectly controlled by the length and diameter of the bottle-neck connecting the vaporizer with the combustion space of the cylinder. The explosion of the charge takes place entirely within the vaporizer, the piston being protected by a layer of pure air, drawn into the clearance space; this is proved by the absence of tarry gummy matter on the piston rings.

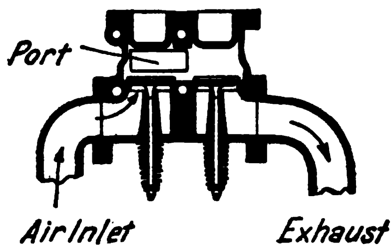


FIG. 117.—HORNSBY-AKROYD ENGINE.
Longitudinal Section through Valves.
(Paragraph 287.)

Governing is accomplished by allowing a greater or lesser amount of the oil, displaced by a positively-driven pump-piston, to flow back to the oil reservoir, usually located in the base plate of the engine. This is effected by means of a governor which opens a by-pass when the speed of the engine temporarily increases. If the engine is required to run for any considerable length of time under less than full load, the stroke of the pump can be readily adjusted to the load carried by the engine.

In starting, it is advisable first to light the Bunsen burner used for heating the vaporizer and place it on a stand of proper

height just beneath the latter; the vaporizer being protected from the cooling effect of air currents by a movable hood. While the vaporizer is being heated, the oil cups may be filled and the cam-lever shifted to the position for starting. When this is done, the smaller engines can be turned over by hand.

Engines above 25 horse-power are provided with a self-starting device, operated by compressed air, on opening the valves between the receiver and the engine, and putting the starting lever into the charging position, the engine itself being used to pump a pressure of 80 to 100 pounds in the starting tank.

Both the air inlet and the exhaust valves are placed on the side of the cylinder, the former being operated by suction or atmospheric pressure, and the latter by means of worm gearing on the secondary shaft. The secondary shaft also operates the oil pump which injects the fuel oil into the combustion chamber.

This engine is principally made in the horizontal type, with single or twin cylinders. In the United States it is constructed by the De La Vergne Machine Co., in sizes ranging from $1\frac{1}{2}$ to 125 horse-power per cylinder; and in England as large as 500 horse-power per cylinder.

238. **The American Diesel.** As stated in paragraph 65, this engine is designed to operate on solid, liquid, or gaseous fuel, but up to the present time it has been chiefly developed as an oil engine.

Fig. 118, shows a vertical section through the crank case and cylinder, and *Fig.* 119, a section through the fuel, air, and exhaust valves.

Referring to *Fig.* 118, the operation of the engine may be described as follows:

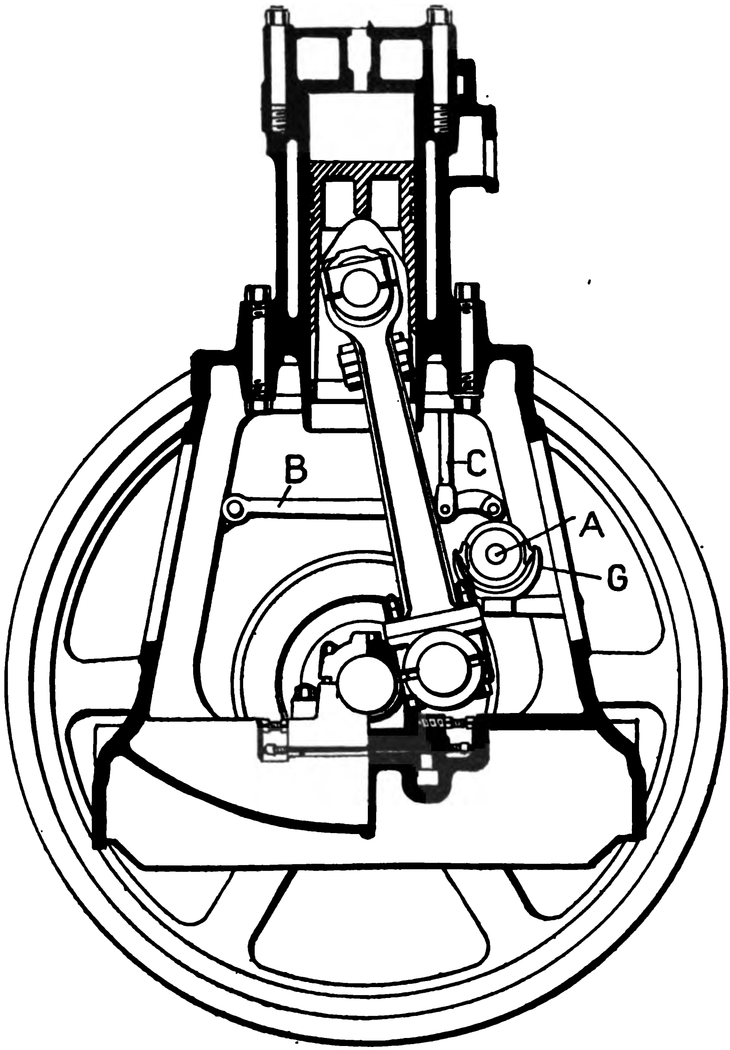


FIG. 118.—AMERICAN DIESEL ENGINE.
Vertical Section through Crank Case and Cylinder.
(Paragraph 288)

Through gearing, the main shaft drives a cam shaft, A, which carries the valve cams and is supported by end bearings in the engine housing. Two cams operate the admission and exhaust valves by means of nearly horizontal arms, B, pivoted at one end to the housing, and carrying rollers which are in contact with the cams. These arms are held down by springs, and the vertical valve rods, C, rest upon and are moved by them.

The compressed air, from the auxiliary compressor, comes through the pipe, D, *Fig.* 119, into the same space but behind the oil delivered from the oil pump through a pipe at the side.

The valve spindle is surrounded by a series of brass washers which are perforated with numerous holes parallel to the axis of the spindle. The oil occupies the cavities between these washers, and by capillary action finds its way into the perforations. When the fuel valve is opened, the compressed air drives this oil out, through the perforations, in the form of a fine spray, into the cylinder where it is instantaneously ignited by the high temperature of the air compressed into the clearance space by the upstroke of the piston.

The clearance space is only about 7 per cent. of the cylinder volume, so that the air for combustion drawn into the cylinder through the poppet valve, E, is compressed on the upstroke of the piston to a pressure ranging from 450 to 525 pounds per square inch, with an accompanying compression temperature of about 1000° Fahr., which is much more than sufficient to ignite the oil the instant it is injected into the cylinder.

At the beginning of the power stroke, the fuel valve opens and remains open for about a tenth of the stroke, and the combustion of the oil admitted continues during the whole or a portion of this period according to the action of the governor. After

the fuel supply is cut off, the working substance, air, expands adiabatically during the remainder of the stroke, until the products of combustion are discharged from the cylinder by the opening of the exhaust valve, F, the terminal pressure being but slightly greater than that of the atmosphere.

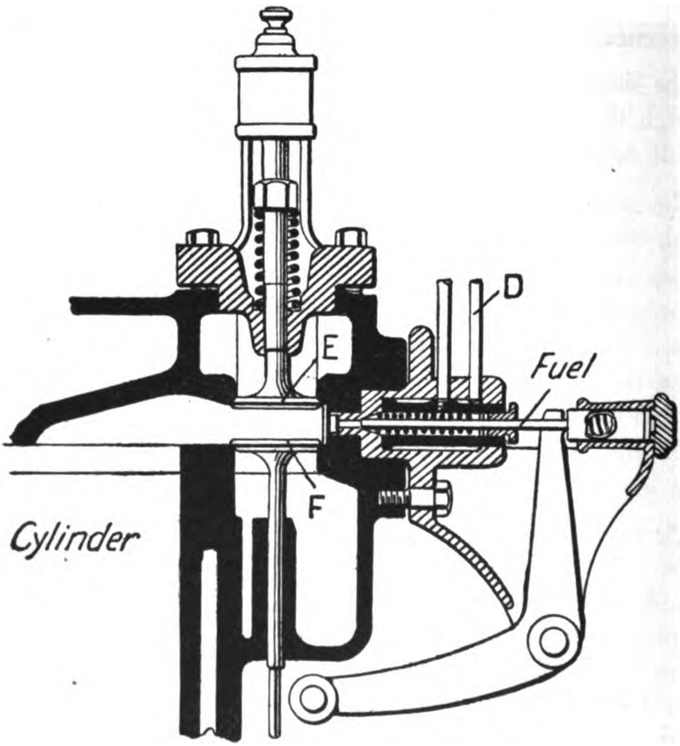


Fig. 119.—American Diesel Engine.
Section through Fuel, Air, and Exhaust Valves.
(Paragraph 238)

Governing is accomplished by regulating the quantity of oil fed to the fuel valve during each stroke by means of an oil pump driven from the cam shaft. In the multi-cylinder en-

gines, each power cylinder is provided with a separate pump cylinder, and a valve, which, when open, acts as a by-pass and permits the oil to return to the suction side of the pump instead of flowing to the fuel valve of the engine. The by-pass valves are kept open by the action of the governor during a greater or lesser part of each stroke according to the load on the engine. These valves are opened by arms, pivoted at one end on a shaft which is raised or lowered by the governor, deriving their motion from rods connected to eccentrics on the pump driving shaft. The short link from the governor collar to the crank on the shaft carrying the valve opening arms, transmits the motion of the governor to the shaft, thus raising or lowering the shaft so as to increase or decrease the distance between the top of the by-pass valve rods and the arms which open the valves. By this arrangement, the interval of time during which the oil valve remains open, and consequently the quantity of oil pumped to the admission valves of the cylinders, depends on the relative distance between the top of each valve rod and its corresponding opening arm, as determined by the action of the governor. The admission valve, however, always remains open a constant length of time regardless of the action of the governor, but, except at full load, fuel is fed into the cylinder during a part only of the time the valve is open, the commencement of the expansion curve on the indicator diagram marking the time when the fuel supply is interrupted. Compressed air alone, blows by the valve during the remainder of the time it is open.

The cylinder walls, cylinder heads, and all valves are water-cooled. The pistons are very long, the connecting rods of the marine type, and the main bearings are adjustable by wedges and screws.

The lubrication is automatic. The massive housing entirely incloses the reciprocating parts, and is provided with removable doors in the side giving easy access to the interior for purposes of adjustment and repair.

Starting is effected by means of compressed air furnished by an auxiliary reservoir. A handle outside the housing throws

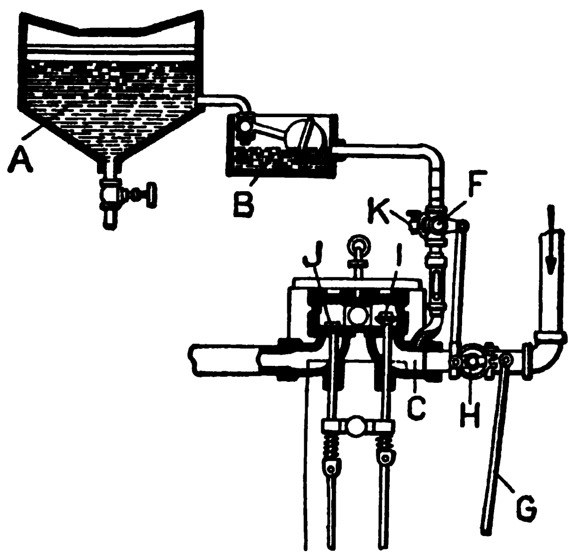


FIG. 120.—SECOR OIL ENGINE.
Gravity Feed Arrangement.
(Paragraph 289)

the fork, G, *Fig.* 118, so as to move the valve cams of the first cylinder along the cam shaft, and bring into action a starting cam which operates a starting valve. This valve merely admits compressed air into that cylinder, for one or two revolutions, until the compression in the other cylinders is sufficient to ignite their charges. The handle is then released, so that, while

the starting cam is thrown out of action, the admission and exhaust cams of the first cylinder are again thrown into action.

This engine is built in the vertical, single or multi-cylinder types in sizes ranging from 75 to 450 horse-power.

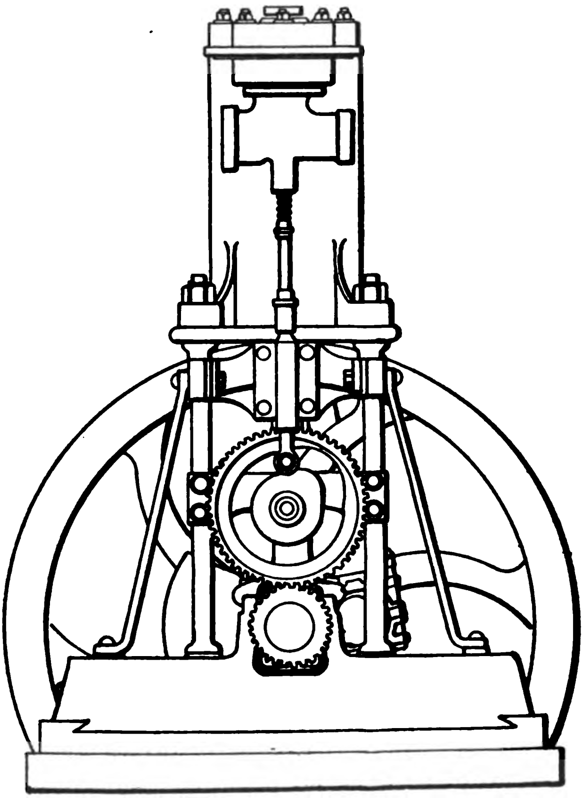


FIG. 121.—SECOR OIL ENGINE.
Side Elevation. (Paragraph 239)

239. **The Secor.** This engine has neither atomizer nor vaporizer, nor does it use any pumping device for injecting the oil into the cylinder. A gravity feed is employed to maintain

a constant level of the oil supply above the cylinder by means of a float, as shown in *Fig.* 120. The main reservoir, A, supplies oil to the tank, B, in which the float valve is mounted.

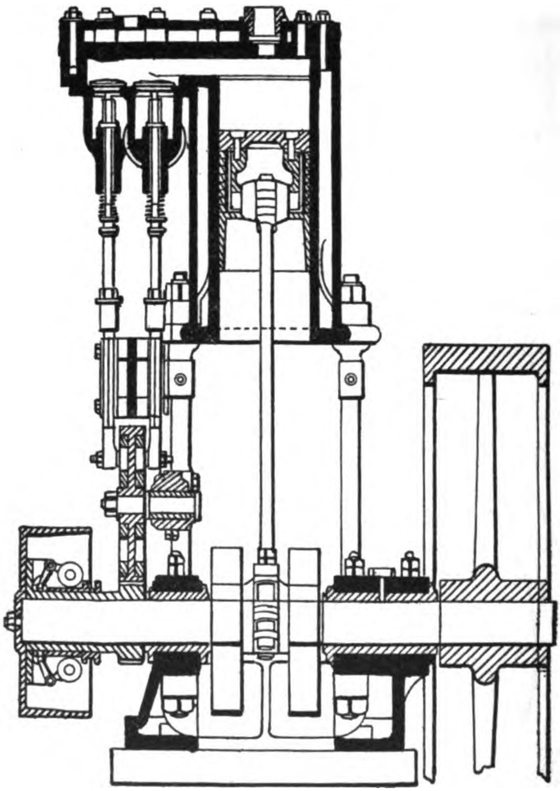


FIG. 122.—SECOR OIL ENGINE.
Vertical Cross Section through Cylinder and Valve Chambers.
(Paragraph 289)

The oil is delivered by gravity from the tank, B, to the inlet pipe, C, passing through the regulating cock, F, the opening of which is controlled by the governor through the rod, G, which

also controls the volume of air admitted by operating the air cock, H. Both the admission valve, I, and the exhaust valve, J, are operated by cams on the secondary shaft in the usual manner. The proportion of air to oil is regulated by means of a micrometer worm at K, which shifts the fuel valve, F, with respect to the valve lever actuated by the governor. By this arrangement, it is possible to vary the quality of the mixture forming the charge, according to the grade of oil used, while, on the other hand, when the adjustment at K, is once made, the proportion of air to oil remains constant, regardless of variations in the load, and the consequent throttling of the charge by the governor.

Ignition is effected by the jump-spark method, with primary batteries supplying the current for the spark coil.

Fig. 121, shows a side elevation of the engine, and *Fig.* 122, a vertical section through the cylinder, valve chambers, and crank shaft.

CHAPTER XXI.

MARINE ENGINES.

240. Marine Terms. The *"bow"* is the extreme forward part of the vessel. The *"stern"* is the extreme after part of the vessel. *"Amidships"* is the central part of the vessel. *"Forward"* is the part between amidships and the bow. *"Aft"* is the part between amidships and the stern. *"Starboard"* is the right hand side of the vessel looking forward. *"Port"* is the left hand side of the vessel looking forward.

241. Working Principles of Marine Engines. The various types of gas, gasoline, and oil engines used for marine purposes operate on the four-cycle or the two-cycle principle, as explained in Chapter IV, and are usually of the vertical single or multi-cylinder, and single or double-acting type.

In the general arrangement and construction, they very closely resemble corresponding types of automobile motors, but they are made very much heavier so as to enable them to withstand the wear and tear incident to continuous operation under full power, a service seldom required of the automobile engine.

They are being built in sizes ranging from 1 to 1,000 horse-power,—the 1 to 20 horse-power engines being suitable for various types of motor boats, the 20 to 100 or more horse-power for launches and small yachts, and the larger sizes for torpedo boats, destroyers, small cruisers, tugs, and ferryboats in the naval service.

In the last named cases, the successful introduction of suitable gas producer systems is one of the assured features of the developments in this line in the immediate future.

At the present time, the demand for motor boats, launches and small cruising yachts, propelled by internal combustion engines, is increasing at a rapid rate, and is accompanied by a demand for larger engines. In the case of the smaller sizes, the simplicity of construction, and the reduction in the number of working parts, tend to make these engines practically automatic in their action, so much so, that they may be readily handled by any one who has received brief but specific instruction as to their operation. Nevertheless, it is also true, that like those of the larger sizes their successful and continuous operation largely depends upon their proper management.

It is well to understand in this connection, that the relative merits of the two types of engines,—the four-cycle and the two-cycle, is one of the questions relative to internal combustion engines which still remains practically undecided. A great deal can be said in favor of and against each type, on both theoretical and practical grounds, but as the majority of engineers do not appear to be quite unanimous in their methods of computing mechanical efficiency, it is very difficult if not impracticable to make a decisive comparison of the two types just at the present stage of their development. It is quite probable that engines of either type built by the best manufacturers will give equally satisfactory service under general working conditions.

242. **Essential Requirements of a Marine Engine.** The most extended experience and careful observation indicate the following named requirements as essential for the successful operation of a marine internal combustion engine:

1. They should be capable of being easily started, readily controlled and quickly reversed.

2. Small sizes may be either single or double-acting. Large sizes ought to be double-acting. All engines ought to be of the vertical type.

3. They ought to be provided with reliable governors, preferably of the throttling type, which will prevent them from racing in a seaway or when reversing.

4. Every part of the engine exposed to heat should be amply water-jacketed, and suitable means should be provided for maintaining the temperature of the cooling water within a few degrees of the highest point necessary for effective lubrication.

5. All governors, cams, and other working parts should be inclosed to prevent rattling noises, and all valves should be inclosed in sound-deadening pockets.

6. All engines should be provided with properly constructed mufflers to deaden the objectionable noises caused by the explosions and the exhaust.

7. The engine should be properly balanced, and equipped with very heavy fly wheels to prevent vibration.

8. The ignition should be electric, starting being effected by battery current, and subsequently by spark furnished by a sparking magneto.

9. The gasoline should be stored in a strong copper tank, well braced and divided by partitions to prevent washing about.

10. The engines should be provided with carburetters of the float-feed type which will generate the proper mixture of gasoline vapor and air under all conditions regardless of the speed of the vessel, and maintain a constant level of gasoline regardless of the pitching of the vessel in a heavy seaway.

11. All engines should be equipped with reversing gear of the friction clutch type operated by means of a single lever.

The gears should always be in mesh so as to prevent sudden jars when reversing quickly.

12. The bore of the cylinder should be about equal to the stroke of the piston.

243. **Working Parts of a Marine Engine.** The essential parts of a marine internal combustion engine are practically the same as those of corresponding types of stationary engines, but suitably modified to meet the demands of their particular service. The details of construction vary more or less in the different makes, to such an extent, that it is practically impossible to formulate a general description, which will be applicable to all with respect to the detailed arrangement of their minor working parts. It is practicable, however, to give a general description of the principal working parts of a two-cycle marine engine, which, when taken in connection with the subject matter of Chapter IV, relative to the operation of four-cycle engines, and the brief descriptions of some of the standard makes of marine gasoline and oil engines given in this chapter, will afford a comprehensive knowledge of the construction, peculiarities, and methods of operation of the various types of marine engines in general.

244. **Principle of Operation of a Two-cycle Marine Engine.** Referring to *Figs.* 123 and 124, showing vertical transverse cross sections through the cylinder and crank case of a two-cycle engine, and *Fig.* 125, showing a longitudinal section through the crank shaft, the operation of the engine may be described as follows:

The suction caused by the upstroke of the piston, A, draws a charge of vaporized gasoline and air through the vaporizer inlet, B, into the interior of the crank case or crank chamber,

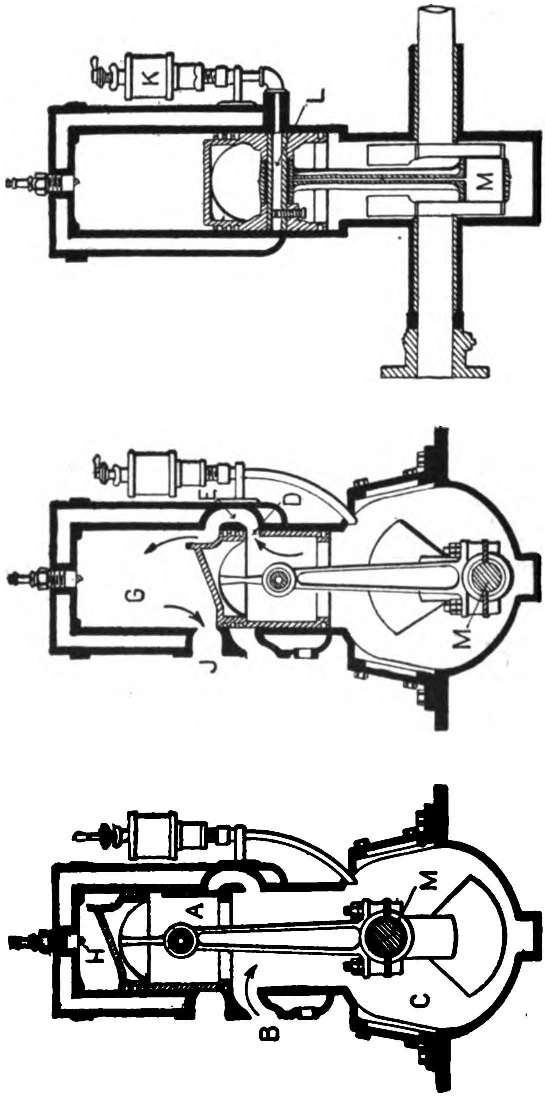


FIG. 123. FIG. 124. FIG. 125.

PRINCIPLE OF OPERATION OF A TWO-CYCLE MARINE ENGINE.
(Paragraph 244)

C, *Fig.* 123. This charge is compressed in the crank chamber by the following downstroke, and as the piston reaches the lower limit of this stroke, it brings the admission port, D, opening into the hollow of the piston, opposite the by-pass, E, *Fig.* 124, communicating with the crank chamber, thus permitting the charge in the crank chamber to pass into the combustion space, G, of the cylinder.

The next upstroke of the piston compresses the charge into the compression space at the top of the cylinder where it is ignited by a spark at the lower end of the spark plug, H, *Fig.* 123. The force of the resulting explosion drives the piston downwards on its power stroke, and as the piston passes the exhaust port, J, *Fig.* 124, the products of combustion are exhausted from the cylinder; a fresh charge, compressed into the crank chamber by this stroke, is again allowed to pass through the port, D, and the by-pass, E, into the combustion space, G. The momentum of the fly-wheel then carries the piston upwards on another compression stroke, so that the entire cycle of operations is repeated, giving a power stroke at every revolution of the crank shaft.

The method of lubrication is illustrated by *Fig.* 125. In the case of the crosshead, piston, and cylinder walls, the lubricating oil is carried directly from the cylinder lubricator, K, through the passage, L, in the hollow piston pin; and in the case of the crank-pin, M, the revolving crank-pin connections take up the oil fed into the crank chamber through the pipe leading from a separate sight feed lubricator placed on the crank chamber.

245. Fairbanks Marine Gasoline Engine. These engines are built in the vertical single or multi-cylinder type and operate on the two-cycle principle.

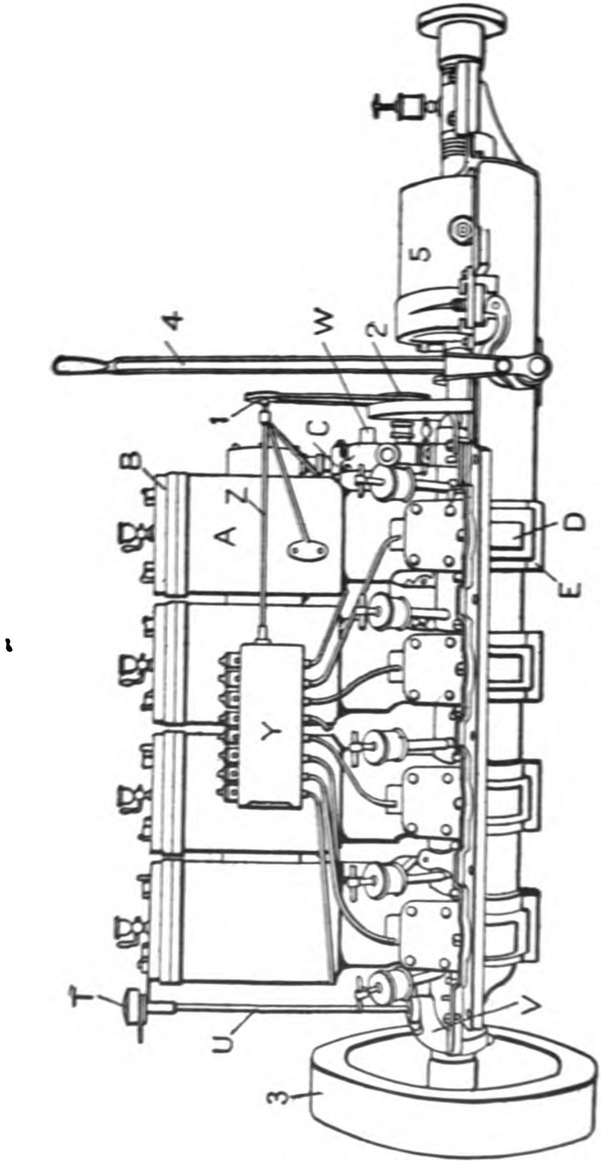


FIG. [illegible].—FAIRBANKS GASOLINE MARINE ENGINE; PORT SIDE.
(Paragraph [illegible])

Fig. 126, shows the port side, and *Fig.* 127, the starboard side of the four-cylinder 28-35 horse-power engine, and *Fig.* 128, a vertical section through one of the cylinders.

Referring to Fig. 126, the cylinder, A, the cylinder head, B, and crank case, C, constitute the principal castings. The cylinder proper is a separate casting from the bed plate, and when attached to the latter forms the crank case. The two halves of the crank case are put together and held in alignment by means of steel dowels, and each crank case is provided with hand holes, D, which admit of easy access to the crank connections. The lower part of the crank case terminates in a pocket, E, provided for catching small particles of dirt or grit, which together with surplus or dirty oil can be drawn off by means of a small brass drain cock. The cylinder casting, cylinder head, exhaust pipe casting, and the gas inlet pipe, G, *Fig.* 127, are all completely water-jacketed. The cylinder head is secured to the cylinder by means of steel studs and case hardened nuts, and two small lifting screws are attached to each head by which they can be lifted away from the cylinder whenever necessary, without the use of wedges which scar the castings and break the gaskets.

The piston, H, as shown in *Fig.* 128, has an oblique upper surface which serves to sweep out the products of combustion while the piston admission port, I, when opposite the by-pass, J, permits of the quick entry of the fuel gas into the combustion chamber, K.

The passage of the cool fresh charge through the hollow piston not only tends to reduce the temperature around the piston pin, L, but lowers the temperature of the entire surface of the piston to a point sufficiently low for effective lubrication. Each piston is provided with four piston rings, M, three at the

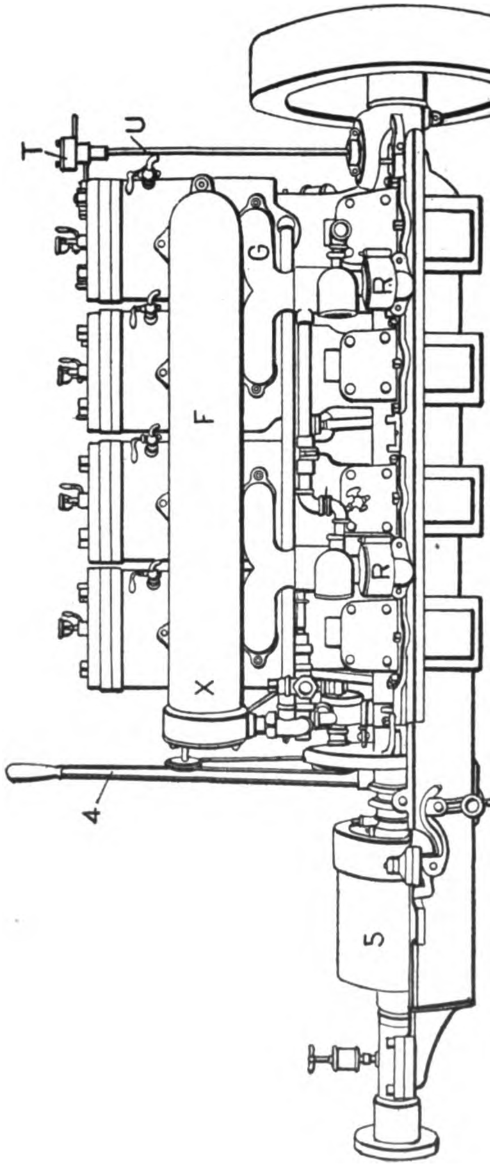


FIG. 127.—FAIRBANKS GASOLINE MARINE ENGINE; STARBOARD SIDE.
(Paragraph 245)

top and one at the bottom, carefully ground and fitted to a fraction of one-thousandth of an inch. The piston pin, L, is of hardened steel. It is hollow, and thereby provides the oil passage for the lubrication of the piston, cylinder walls, and its own bearing.

The connecting rod, N, is made of forged steel, and is designed to give the greatest possible strength without adding materially to the total weight of the reciprocating parts. The piston pin bearing is an interchangeable bushing of phosphor bronze, and the bearing on the crank pin is made of Babbitt metal. The crank pin connection, O, is secured by stud bolts with nut and lock nuts, the latter being secured by steel split pins, and afford the means for taking up wear due to continuous service.

The crank shaft is forged from a solid ingot of high carbon steel, turned and ground accurately to size. All cranks are provided with counter balances as shown at, Q.

These engines will operate successfully on any grade of gasoline from 62 to 88 degrees Beaumé, and will consume from 1 pint to 1⅓ pints per horse-power-hour.

They are equipped with carburetters, R, *Fig.* 127, of the float-feed type, provided with a throttling lever by means of which the speed can be quickly and easily regulated.

Ignition is by jump-spark, the principal parts of the electrical equipment being a battery, either dry or storage, a vibrator or spark coil, timer, spark plugs, S, *Fig.* 128, switch and wire.

The jump-spark coils are of the dashboard type used on the better classes of automobiles. In each case the coil is covered with insulating material which is unaffected by variations of temperature, and the entire arrangement is placed in a box

having a close fitting cover which protects the electrical parts from contact with dirt and water.

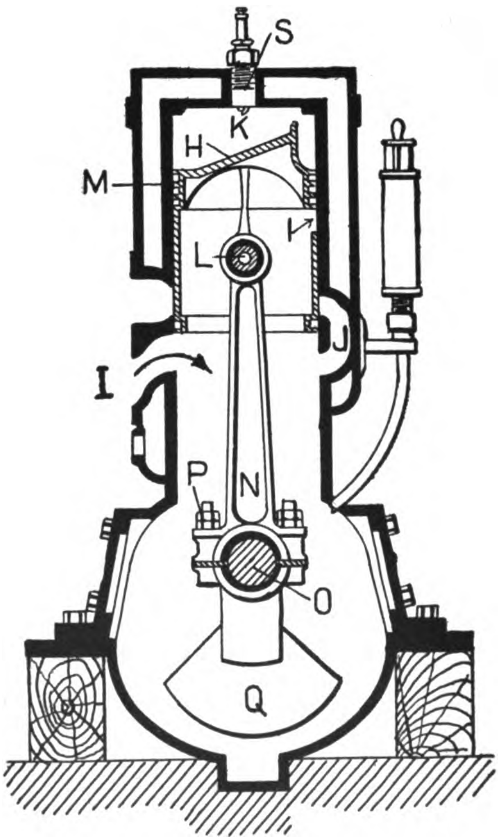


FIG. 128.—FAIRBANKS GASOLINE MARINE ENGINE.
Vertical Section through one Cylinder.
(Paragraph 245)

The timer, T, *Figs.* 126 and 127, is of the rotary type and consists of a hard-rubber case containing the contact points,—two hardened steel balls placed one above the other. Operating

between these balls is a steel knife or cam mounted on ball bearings. The cam is actuated by a bronze shaft, U, driven by bevel wheels incased in a brass gear case, V, located above the crank shaft directly aft of the fly wheel. A friction lever attached to the timer case permits the regulation of the spark for all cylinders.

The spark plugs are of the porcelain insulated type, and are provided with separate terminals for connecting the secondary wire to the plug. These terminals are of the clip pattern, and may be removed for examination by unscrewing the brass bushing only, which at once releases the whole plug, with the exception of the shell, from the cylinder. The spark plugs are completely covered with porcelain hoods which protect them from heavy rain or seawater if the engine is used in an open boat. Each hood has a neck, one side of which is recessed for the introduction of the clip terminal, which engages the slot of the brass cap of the spark plug. A piece of rubber tubing covers a portion of the insulation of the secondary wire and ferrule end of the terminal. It is of sufficient length to be stretched over the neck of the hood, thus making a perfectly watertight connection. The entire arrangement carries the insulation from the wire down over the spark plug to the cylinder head, and thus obviates all possibility of short circuiting. This device is unnecessary on engines placed under cover.

On the single cylinder engines, the cooling water is pumped by means of plunger pumps operated by the eccentric rods. The multi-cylinder engines employ a rotary pump, W, *Fig.* 126, especially adapted for pumping dirty water, and driven by two brass spur wheels directly from the end of the crank shaft. The pump is equipped with a three-way cock which gives it the double capacity of a bilge pump and a seawater pump.

By turning this cock in one direction the water supply is drawn from the sea, and by turning it in the opposite direction the bilge water can be pumped out of the boat. Drain cocks fitted to the lower part of the cylinders and the water-cooled exhaust pipe connections, X, permit the drawing of the water from the water jackets, piping, and pumps, in freezing weather.

The cylinder and crank case lubricators are of the sight feed type. The multi-cylinder engines are equipped with a force-feed oiler and oil reservoir, Y, carrying on its top the sight feed glasses which enable the operator to see the amount of oil that is being fed to any particular bearing. Adjusting screws are attached to the top of the reservoir, by means of which the flow of oil to the bearings can be individually regulated. The action of the oiler depends upon that of the shaft, Z, which leads to the reservoir and operates a series of small pumps which force the oil directly to the bearings. The shaft is operated by the belt-driven pulleys 1 and 2, *Fig.* 126, operated from the crank shaft, thus giving an automatic delivery of oil in proportion to the speed, and a cessation of oiling when the engine stops.

Starting is effected by turning the fly wheel, 3, *Fig.* 126, by hand, cranking being unnecessary. The larger engines are, however, provided with a ratchet turning gear, so as to overcome the higher compression. After starting, the speed is regulated by automatic action of the carburetter and the spark control.

The noise of the exhaust is deadened by means of a muffler of the injector type.

When a solid bladed propeller is used, reversing is accomplished by means of a reversing lever, 4, *Fig.* 126, which operates the gearing and friction clutch mechanism shown at,

5. The clutch is directly connected and always remains in perfect alignment, the wheels revolving idly with the shaft when going ahead. For backing, the reversing lever is thrown so as to release the clutch, and a reversed motion is imparted to the propeller through the bevel gearing.

246. The Meitz and Weiss Marine Engine. In general construction and operation, this engine is similar to the stationary engines built by the same manufacturers and described in paragraph 236, and operates with kerosene, distillate, residuum or crude oil. It is of the vertical single or multi-cylinder type, and is built in sizes ranging from 1½ to 100 horse-power.

Fig. 129, shows the starboard, and *Fig.* 130, the port side of a two-cylinder engine, and *Fig.* 131, a vertical section through one of the cylinders.

All the principal stationary and working parts of the engine are lettered and named on the figures, and, as already stated, the principle of operation is exactly similar to the stationary horizontal engines described in paragraph 236.

To start the engine, unscrew the funnel cap of the burner cylinder, E, *Fig.* 130, open the gauge cock, 6, *Fig.* 131, and fill the vessel three-quarters full through the filler, R, *Fig.* 131, until oil runs out of the gauge cock. Pump up the compressed air tank, turn on the air valve, and light the burner with the torch furnished for that purpose. Regulate the air pressure by means of the needle valve so as to obtain a strong but short flame. Five minutes is usually sufficient to bring the igniter ball to a dull red heat. In the case of a multi-cylinder engine, this operation must be performed in connection with each cylinder.

When the igniter balls have attained the proper temperature, open the relief cocks, M, *Fig.* 129, on the compression chambers of the cylinders, and turn the fly wheel over until the handle is opposite the governor gear; close the relief cocks; open the throttle about two-thirds; pump one or two charges of oil into the cylinders by pressing quickly down on the pump

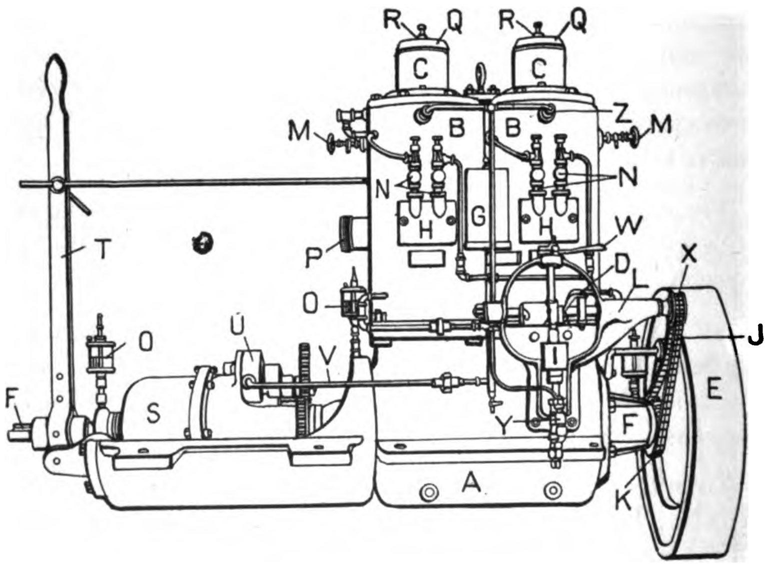


Fig. 129.—Meitz and Weiss Engine; Starboard Side.
(Paragraph 246)

A—Crank Case.
B—Cylinder.
C—Mantle.
D—Governor Weight.
E—Flywheel.
F—Crank Shaft
G—Lubricator Oil Reservoir.
H—Port Covering Plate.
I—Oil Supply Pump.
J—Governor Chain.
K—Governor Chain Gear.
L—Governor Bracket.
M—Relief Cocks.
N—Sight-Feed Lubricators.
O—Lubricator Oil Wells.
P—Exhaust Fitting.
Q—Dampers.
R—Damper Screw Holders.
S—Reversing Gear.
T—Reversing Lever.
U—Circulating Water Pump.
V—Circulating Water Pipe Connection.
W—Oil Pump Handle.
X—Idler Bracket.
Y—Suction and Pressure Valves.
Z—Injection Pipe.

handle, W, *Fig.* 129, then rock the fly wheel a few times to the right against the compression until an explosion is obtained which will drive the piston forward.

After the engine has been started, the throttle can be opened wide so as to allow it to attain full speed.

Should the engine start backwards, hold the pump lever down until it slows down, then forcibly inject a charge of oil

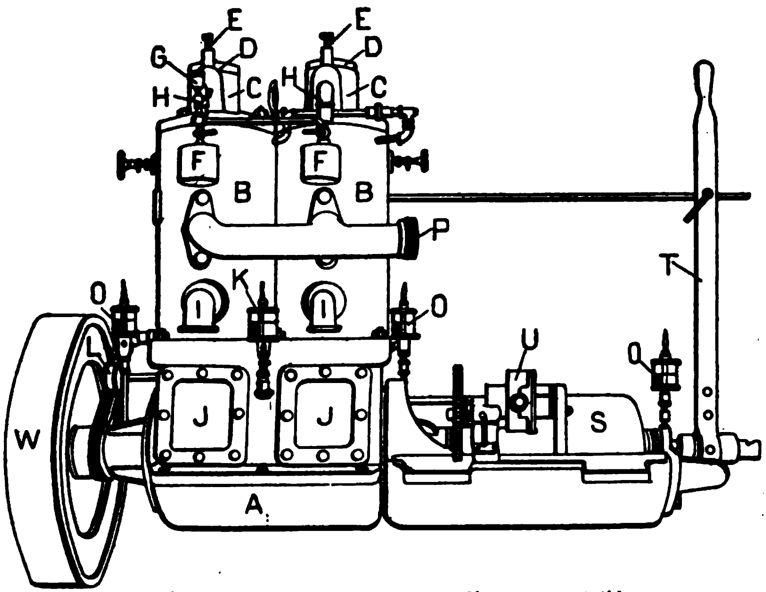


FIG. 180.—MEITZ AND WEISS MARINE ENGINE; Port Side.
(Paragraph 246)

A—Crank Case.
B—Cylinders.
C—Mantles.
D—Dampers.
E—Damper Screw Holders.
F—Burners.
G—Burner Filler.
H—Burner Blow-pipe.
I—Air Inlet.
J—Crank Case Plate.
K—Center Bearing Oiler.
L—Idler.
M—Relief Cocks.
O—Lubricator Oil Wells.
P—Exhaust Fitting.
S—Reversing Gear.
T—Reversing Lever.
U—Circulating Water Pump.
W—Flywheel.

A—Crank Case.
B—Cylinder Proper.
C—Water Jacket.
D—Piston.
E—Connecting Rod.
F—Wrist Pin.
G—Crank Pin.
H—Center Bearing.
I—Air Inlet.
J—Exhaust Fitting.
L—Mantle.
M—Damper.
N—Damper Screw Holder.
O—Igniter Ball.
P—Burner Blow-pipe.
Q—Burner.
R—Burner Filler.
S—Injector Nozzle.
T—Water Feed Pipe.
U—Oil Supply Pump.
V—Oil Pump Handle.
W—Flywheel.
X—Crank Case Plate.
Y—Connecting Rod Box.
Z—Suction Pipe.
1—Sight Feed Lubricator.
2—Center Bearing Lubricator.
3—Center Bearing Lubricator Set Screw.
4—Regulator Handle.
5—Governor.
6—Burner Gauge Cock.

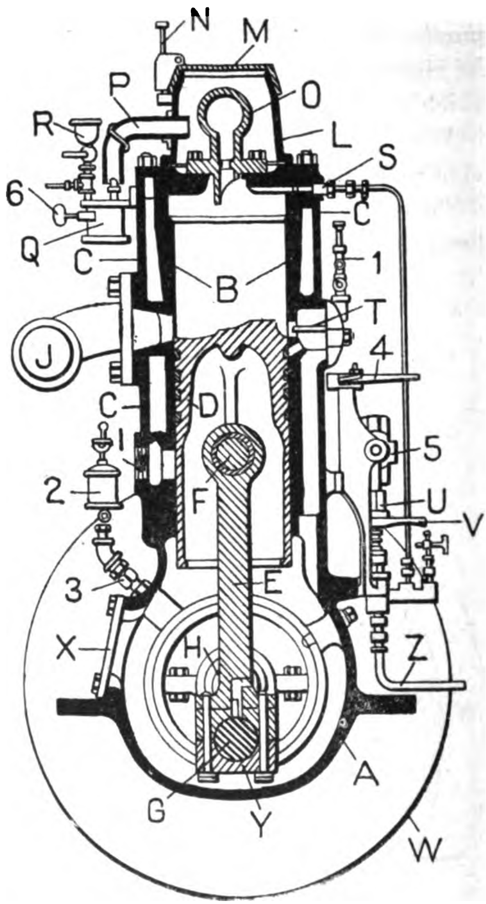


FIG. 131.—MEITZ AND WEISS MARINE ENGINE.
Vertical Section through one Cylinder.
(Paragraph 246)

from the pump into the cylinder, and the motion of the engine will be reversed.

To stop the motor, push in the throttle so as to throw the oil pump out of action, turn water sight feeds on and off, then close tightly.

247. **Friction Clutch Reversing Gear.** Some efficient type of reversing gear must be fitted to every marine engine so that the vessel may go astern promptly, if necessary. As the operation of an explosion motor is entirely different from that of a steam engine, the former is generally permitted to run continuously in one direction; the reversal being effected by means of the transmission gearing. Some small craft have screws whose blades may be reversed at will, from one hand to the other, thus producing sternward motion with the same direction of rotation. Most boats have solid propellers and are then fitted with a friction clutch gear, a good type of which is shown in *Fig.* 132.

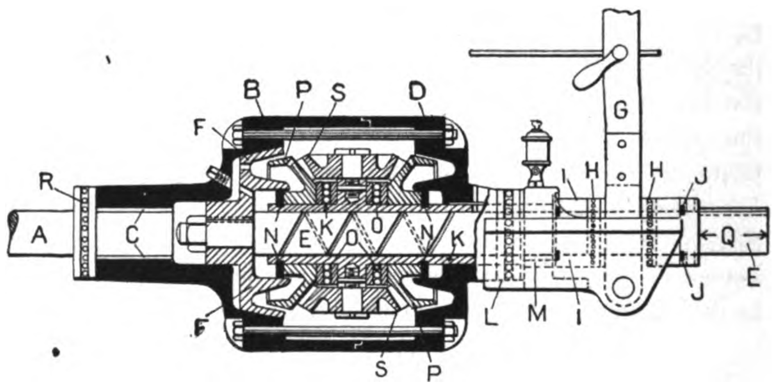


FIG. 132.—FRICTION CLUTCH REVERSING GEAR.
(Paragraph 247)

The crank shaft, A, is keyed to the casing, B, by the keys, C. The casing, B, is rigidly bolted to the casing, D. The stub shaft, E, carries at its inner end the friction cone, F, which engages the inner friction surface of the casing, B. The stub shaft, E, is movable longitudinally by means of the lever, G, and the yoke rings held between the roller bearing thrust collars, I and J; the collars, J, being locked in a circular groove

on the shaft. The bronze sleeve, K, moves longitudinally in the casing and outer bearing, L, the feather, M, in the bearing, L, serving to prevent rotation. The sleeve, K, carries two bevel wheels and two bevel pinions. The two wheels, PP, are held between the collars, NN, and the ball thrust-collars, OO, but are capable of free rotation. The wheels, PP, have coned friction surfaces which engage the friction cone, F, and the inner surface of the casing, D, respectively. The propeller shaft is connected to the projecting part, Q, of the stub shaft, E.

The gear operates as follows: Standing in the *central position,* as shown in the illustration, the engine revolves idly, the propeller shaft remaining stationary. Pushing the lever, G, to the left or *forward,* causes the cone, P, to engage with the inner surface of the cone, F, forcing the latter against the inside of the casing, B. This causes the shaft to run in the same direction as the engine, or *ahead.* Pulling the lever, G, to the right or *aft,* the after cone engages with the casing, D; motion is transmitted through the bevel wheels and pinions, SS, to the inside of the cone, F, causing the latter and consequently the propeller shaft to run in the contrary direction to the engines, putting the boat *astern.*

248. The Naphtha Engine. This engine, although operating on naphtha vapor, is essentially an external combustion engine. That is, a portion of the naphtha is burned in a burner and heats another portion contained in a retort until the vapor tension in the latter is sufficient to operate the engine in a manner exactly similar to that of a steam engine. These engines are made in sizes ranging from 1 to 10 horse-power, and are especially suitable for use in small launches.

As shown in *Fig.* 133, the most prominent feature of the installation is the burner and retort, A, mounted on the housing, B, inclosing the engine, the general construction of which and the principal parts thereof are shown by *Figs.* 134 and 135.

The operation of the engine may be best described by brief instructions relative to its management.

Referring to *Fig.* 133, to start the engine, turn air valve, C, from left to right, and give the air pump, D, a few strokes, from two to five strokes being usually sufficient, to force the gas from the tank into the burner, A, where it can be ignited by a match inserted through the hole, E. Heat the retort by means of the flame thus obtained by keeping up the action of the air pump. In warm weather, use the air pump one or two minutes, but in cold weather, the gas generates very slowly and therefore requires a much longer use of the pump.

When the retort is sufficiently heated, open wide the naphtha valve, F, and give from 10 to 25 quick strokes to the naphtha pump, G, which pumps the naphtha from the storage tank in the bow of the boat to the retort. If the retort has been sufficiently heated, the gauge, H, will at once indicate the pressure attained, which ought not to be more than 20 pounds, for starting. Now open the injector valve, J, which supplies fuel to the burner, and keep the damper, K, partially closed, especially if there be much wind blowing. Then, by means of the wheel, L, which is used for both starting and reversing, turn the engine over several times from right to left and from left to right, proper care being taken in the meantime to prevent the fire or flame in the burner from going out, by giving the pump, G, four or five strokes, as often as necessary, to keep the fire burning so as to maintain a pressure of 20 pounds.

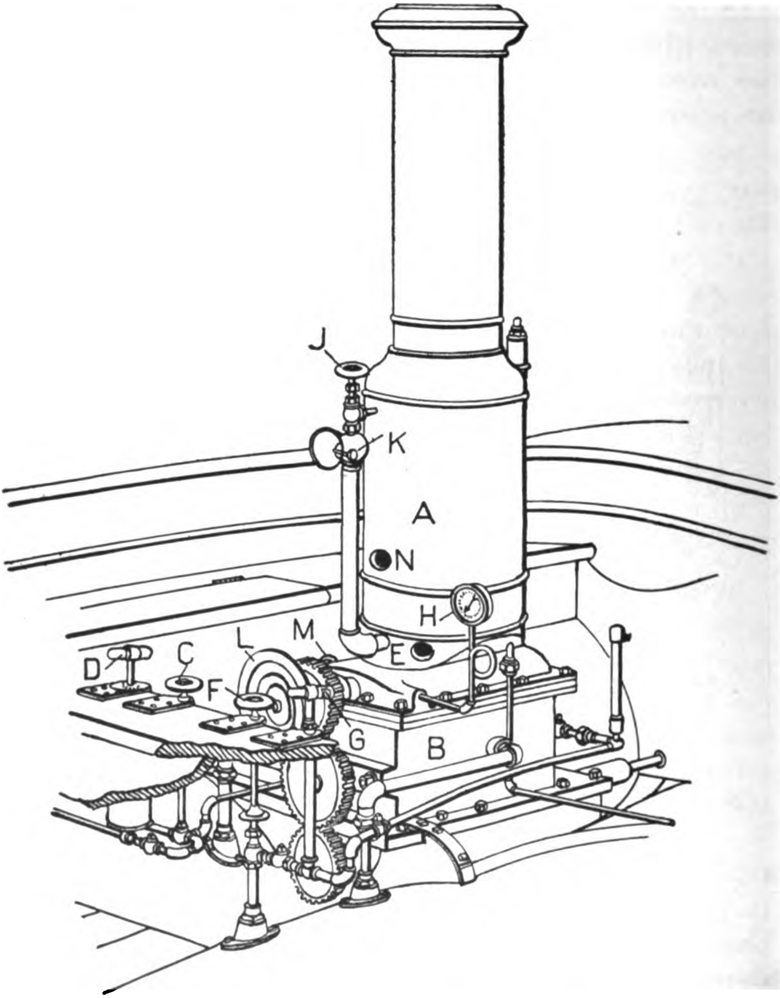


FIG. 133.—NAPHTHA ENGINE INSTALLATION.
(Paragraph 248)

If the fire happens to go out, shut off the injector valve, J, at once; give the air pump, D, a few strokes before relighting; and open the injector immediately afterwards. If the engine turns over hard, block open the safety valve, M, and continue to use the naphtha pump. This operation will allow the pressure to go through the engine and blow out the condensed naphtha collected on top of the piston.

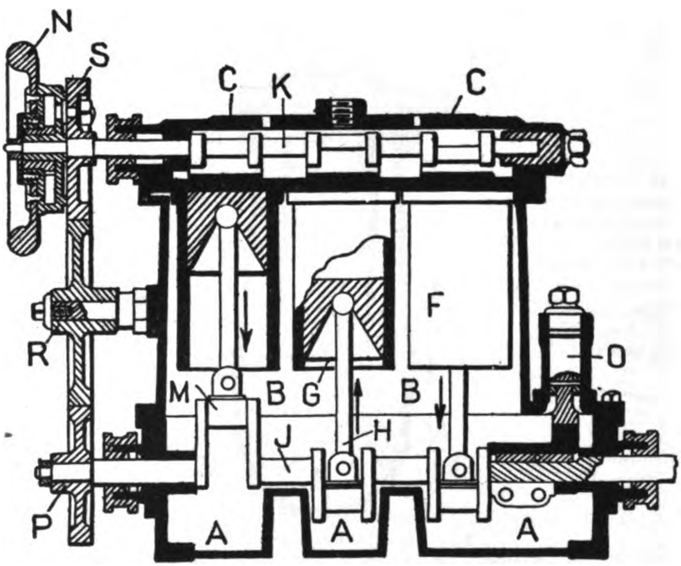


Fig. 134.—Naphtha Engine.
Longitudinal Section.
(Paragraph 248)

To go ahead, turn the wheel, L, to the left; and to back, turn it to the right.

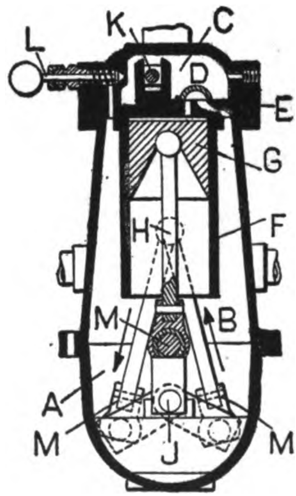
When once started and brought up to the proper speed, the action of the entire arrangement will be perfectly automatic.

While running, the naphtha valve, F, should be left wide open so as to allow free circulation, and it ought to be examined

occasionally to see that the vibration has not closed it and thus interrupted the supply of naphtha.

If it is necessary to increase the pressure at any time, give a few strokes with the naphtha pump and open wide the injector valve and the damper. While running both the speed and the pressure can be regulated by the injector valve, J, and the damper, K, opening to increase and closing to reduce; and

A—Crank Chamber.
B—Exhaust Chamber.
C—Slide Valve Chamber.
D—Slide Valve.
E—Slide Valve Plate.
F—Cylinders.
G—Pistons.
H—Connecting Rods.
J—Crank Shaft.



K—Valve Shaft.
L—Safety Valve.
M—Connecting Rod Crank Boxes.
N—Hand Wheel.
O—Feed Pump.
P—Main Crank Shaft Gear
R—Intermediate Gear.
S—Valve Shaft Gear.

Fig. 135.—Naphtha Engine.
Vertical Cross Section through one Cylinder.
(Paragraph 248)

by them the engine can be reversed instantly and while going at full speed.

The air pump, D, is used for forcing the gas from the tank to the burner, and also for blowing the whistle. To blow the whistle, turn the air valve, C, from right to left.

When running slowly with the injector valve turned down, the damper, K, should be nearly if not entirely closed.

Perfect combustion of the gas in the burner is indicated by a bluish or almost invisible flame, which may be seen at all times through the hole, N, in the jacket. A red flame means imperfect or poor combustion due to too much naphtha vapor and too little air, and indicates that the injector is too widely opened, and the damper not opened wide enough.

To make a landing, close the injector valve, J, and the naphtha valve, F; stop the engine and fasten the boat.

249. **Alcohol Engines.** There are some twenty-four compound substances known to the chemist as alcohols, of which the two most important are *ethyl,* or ordinary alcohol, and *methyl* alcohol or wood spirit.

The former is generally obtained by the fermentation of sugar under the influence of yeast, which converts a sugary solution into carbon dioxide and a mixture of water and alcohol. The percentage of alcohol contained in this natural solution varies according to its origin, wines having from 7 to 15 per cent., beers from 3 to 5 per cent.

The product of fermentation is distilled to make the solution stronger, the flavor and aroma of the spirit depending upon small impurities, native to the source, which are carried over by the distillate. For pure alcohol, the spirit is re-distilled until *rectified spirits of wine* is obtained, which consists of about 84 per cent. by weight of alcohol, the remainder being water. To obtain *absolute or pure* alcohol, the rectified spirits require to be re-distilled several times, owing to the great affinity alcohol has for water.

Any substance naturally containing sugar, such as grapes, fruits, beet roots, molasses, etc., can be readily fermented into alcohol; other substances require first to be transformed into

sugar before fermentation can take place. Thus farinaceous materials, such as potatoes and various cereals, may easily be converted from starch into sugar, and are consequently available as sources of alcohol.

The conversion may be readily effected by treating the starch with acids, forming commercial *glucose,* which may be readily fermented. A more usual method is to saccharify a starchy solution in warm water by the action of *diastase,* a principle present in malt.

Methyl alcohol is obtained from the dry distillation of wood in closed retorts, giving a watery product known as *pyroligneous acid.* This is repeatedly distilled, in conjunction with various re-agents for the purpose of removing various impurities and the contained water, the crude resultant alcohol being known as wood spirit.

Besides its extended use in connection with fermented beverages, alcohol is of great value in the arts and manufactures as a solvent. It is employed in this manner in the manufacture of varnishes, lacquers, smokeless powder, dyes, in the preparation of ether and other medicines, and in the composition of various chemicals. Containing both carbon and hydrogen, alcohol possesses inherent heating properties, which render it valuable as a liquid fuel, where freedom from dirt, odor or smoke is desired. As it is extremely volatile, it is easily vaporized and is therefore available for use in internal combustion engines.

In most countries a heavy tax is imposed upon ethyl alcohol, for revenue purposes, but in England and most countries of Continental Europe, alcohol has long been subject to little or no duty when utilized for industrial purposes. The sole proviso has been that the alcohol should have been first rendered unfit

for use as a beverage before being placed on sale. This process is known as *denaturing,* and is generally effected by means of the addition of a proportion of *wood-spirit,* which is a poison. To prevent the chemist from re-distilling the ethyl alcohol, a proportion of ½ of 1 per cent. of benzine or other hydrocarbon is added, this also adding a perceptible odor.

In 1906, the Congress of the United States removed the tax on denatured alcohol, in order to grant American manufacturers equal opportunities with those enjoyed by their rivals elsewhere, and it is expected that considerable use will be made of the commercial spirit derived from Indian corn, potatoes, beets, refuse of fruit-preserving establishments, etc.

The proportions given for denaturizing by the Act of Congress are:

100	volumes	Ethyl alcohol	(90%)
10	"	Wood spirit	(90%)
½	"	Benzine	(approved)

In England and Germany the denaturants vary, especially in the latter country, as the use of benzine or wood spirit might prejudice the value of alcohol in the preparation of certain substances. In England the proportion of denaturant is legally $\frac{1}{10}$ of the whole.

Since the development of the internal combustion motor, considerable attention has been paid, more especially in Germany and France, to the possibilities of alcohol as a fuel for this type of engine. The native supply of petroleum is slight in the one country and nothing in the other, so there has been every incentive to evolve a successful fuel derived from home-grown products.

Commercial alcohol is never free from water, and the admixture is always spoken of in terms of the percentage by volume of the pure spirit, thus in the preceding formula for denatured alcohol, ethyl is supposed to contain ten per cent. of water, making ninety per cent. spirit.

The presence of water further reduces the heat contents of the fuel, which is estimated to contain from 11,664 to 12,913 B. T. U. per pound when absolutely pure. For 90 per cent. alcohol, these values are reduced to an amount variously stated as between 10,080 and 11,900 B. T. U. per pound. As one pound of gasoline contains 18,000 to 20,000 B. T. U., the heating power of alcohol is not much in excess of one-half that of the other fuel.

On the other hand, careful experiments have shown that, as a working substance, alcoholic vapor has a greater thermal efficiency than the vapor of gasoline, an efficiency of 28 to 31 per cent. having been obtained. This is probably due to the superior compression, as alcohol is not exploded by the same compression pressure as gasoline but can safely withstand a compression of 150 to 180 pounds per square inch. Just as steam from the water jacket is injected into the cylinders of certain oil engines (par. 236), so the vapor from the admixed water is regarded as adding to the useful effect of the machine.

The benzine, added in the process of denaturizing, is regarded as beneficial to explosion engines, as it neutralizes any acetic acid which may be generated by combustion of alcohol, thus preventing corrosion of piston rings, valves, etc.

Any gas or gasoline engine, whether two or four-cycle, may be operated with alcohol by the use of a suitable carburetter, which is the principal element to be regarded in considering the limitations to the use of alcohol as a fuel. With alcohol, the

carburetter requires to be kept at a much higher temperature than with gasoline, and therefore, it is usual to start the engine and run it with gasoline until it becomes well heated, when the gasoline is shut off and the alcohol turned on. For this purpose, two types of carburetters are employed,—the duplex carburetters of the constant level or float feed type, and the atomizing carburetters.

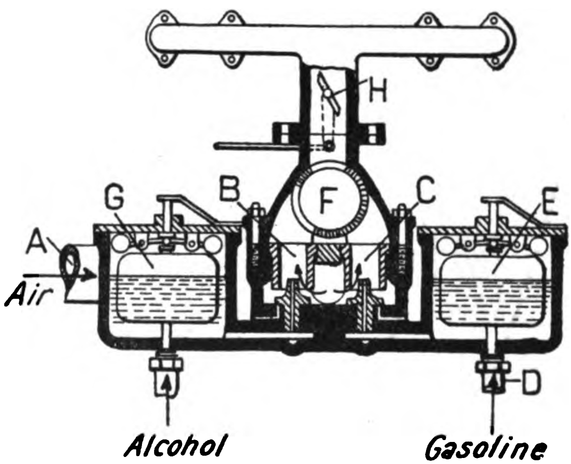


FIG. 136.—MARIENFELDE CARBURETTER.
(Paragraph 249)

Fig. 136, showing a cross section of the Marienfelde carburetter, gives an example of the first type. The air enters through the inlet, A, and surrounds the jets, B and C, in an annular current. The gasoline enters at the inlet, D, and controlled in level by the float, E, passes into the air current through the nozzle at C. The shell valve, F, above the jets is shown in the position required for working the carburetter with alcohol admitted through the float, G, and the jet, B. The engine having been started cold with gasoline, and allowed to

run with that fuel until sufficiently heated, the shell valve, F, is turned to the position shown, thus cutting off the supply of gasoline and turning on the supply of alcohol. The butterfly valve, H, located above the shell valve, operates as a throttle valve to regulate or vary the amount of air and fuel admitted to the cylinder from the carburetter.

Fig. 137, which shows a Martha carburetter, affords an example of the second type. Through the inlet, A, the alcohol enters the spraying chamber, B, and is aspirated by the charging stroke of the engine, together with the air drawn in through the inlet. The alcohol is atomized by contact with the cor-

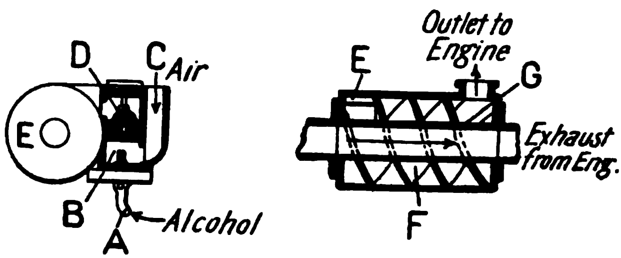


FIG. 137.—MARTHA CARBURETTER.
(Paragraph 249)

rugated surface and the netting of the chamber, D, and passes into the vaporizer, E. The alcohol vapor and air then pass through the spiral channel, F, in contact with the hot exhaust connection, G, and thence out to the engine.

Actual trials, in Germany, of an engine built by Koertings, have shown a consumption of 1.4 pints of 86.2 per cent. alcohol (by weight) per brake horse-power-hour.

Field tests of 120 small engines of three different makes, ranging from 6 to 25 horse-power,* in use by farmers and the like, gave the following results,—the trials extending nearly

over a year, the average length of trial being 996 hours. Only one-fifth of the engines used simple denatured alcohol, 81 per cent. using a mixture containing 20 per cent. of gasoline. The consumption varied from 2.35 pints per brake horse-power-hour, as a maximum, down to a minimum of 0.92 pints, the average being 1.22 pints of the mixture per brake horse-power-hour.

For starting purposes, by the tests of 74 engines of 10 horse-power, it was found that 22½ gallons of gasoline apiece would serve for a year.

As nearly as can be seen at present, the useful effect of a given weight of denatured alcohol is about 0.7 that of an equal weight of gasoline, thus necessitating increased cylinder dimensions in the proportion of 1.4 to 1 to obtain equal powers. This increase of cylinder size and necessary modifications to the carburetter are the only structural differences from gasoline motors.

In view of the many advantages of alcohol, the cost factor is the one chiefly to be reckoned with. It is evident that alcohol should not cost more than about four-fifths the price of gasoline in order to be an effective competitor, save for special uses.

With such trials of alcohol-driven motor cars as have taken place, it has been the practice to mix the denatured alcohol with equal weights of gasoline (petrol). With this mixture ordinary gasoline cars have made creditable performances; on alcohol alone, it would have been necessary to use larger cylinders for the same power, as the heat units are so much less in alcohol than in petroleum spirit.

It is well to understand in this connection, that up to the present time on account of the cost of the fuel, the majority of alcohol engines have been of the condensing type. That is, as

in the case of the alco-vapor engines, the alcohol itself is not burned within the cylinder, but is heated externally in a retort by means of a kerosene burner until it is vaporized, and the vapor tension thus produced is employed to drive the piston, in a manner similar to the operation of a naphtha engine.

250. **Large Marine Engines.** The preceding paragraphs have been exclusively devoted to the consideration of the smaller-sized marine engines, ranging from 1 to 100 horse-power. Successful marine engines of much larger size, ranging from 300 to 500 horse-power are, however, already in successful operation, and marine engines capable of developing 1,000 horse-power are also being built in this country.

The greater number of these engines are of the multi-cylinder double-acting type, operating on the four-cycle principle; and are designed to use either gaseous or liquid fuel, the former being derived from suitable suction gas-producer systems, and the latter from various kinds of fuel oil.

It is important to note that the latest developments in this line are being carefully observed by the naval authorities of various countries, and extensive installations of marine internal-combustion engines are being made by them even at the present time.

In the United States Navy, fourteen vessels, mostly of the submarine type have been equipped with gasoline engines ranging from 10 to 160 horse-power each, and making a total of 1,639 horse-power thus placed in operation. Also four new submarines, one seventy-five foot ferryboat, and two large water barges now under construction, will be equipped with engines ranging from 120 to 250 horse-power each, or a total contem-

plated installation of 1,570 horse-power, giving a grand total of 3,209 horse-power.

Both England and France have made similar installations, and the German navy is building a vessel which is designed to be propelled by a 4,000 horse-power engine.

251. **Advantages of Marine Gas Engines.** The advantages of large marine engines operating on gas, gasoline, or oil, over a steam engine equipment for naval purposes, may be briefly summarized as follows:

1. Equal horse-power with little more than half the weight.

2. An increase in the radius of action from two and a half to three times, by converting the coal into gas.

3. Increased seaworthiness of vessel, especially in the case of torpedo craft, the gain in weight of the machinery being used to greater advantage in the structure of the hull.

4. Ability to attain high speed at night without attracting the attention of the enemy by the glare from the tops of the smoke stacks.

5. Ability to get under weigh quickly without being compelled to maintain a full head of steam at all times.

6. Gain in space by absence of smokestacks, artificial draught arrangements, etc., and freedom from obstructions to the most effective mounting of the armament on the upper decks.

The larger engines usually consist of six cylinders, in which the bore and stroke are equal. *Fig.* 138, is a vertical section through one of the cylinders of a type of double-acting four-cycle engine which is now being constructed by the Standard Engine Company, in sizes ranging from 500 to 1,000 horse-power. The general construction conforms to the best gas engine practice. All the valves are positively operated, water-

cooled, and balanced. The cylinders are amply water-jacketed, and the pistons are cooled by circulating water through the cross head, up a tube in the piston rod, and down a return circuit

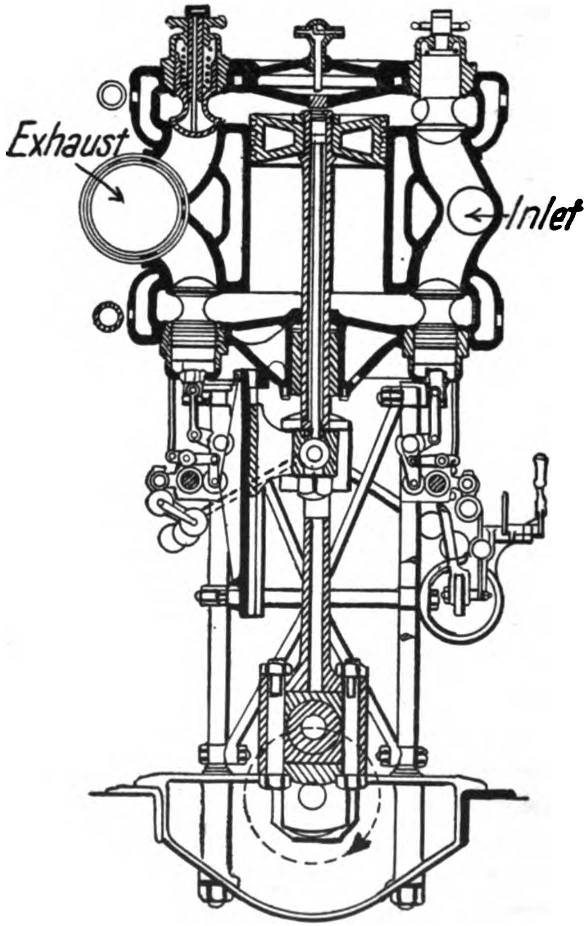


FIG. 188.—DOUBLE-ACTING FOUR-CYCLE GASOLINE ENGINE. 500-1000 Horse-power, Vertical Cross Section. (Paragraph 250)

around the tube. The engine is started by compressed air at a pressure of 250 pounds per square inch, primarily pumped up into two or more air tanks running along the side of the engine room, by means of small auxiliary gasoline engines which not only drive the air compressor, but also the bilge pumps and a small dynamo for lighting purposes and for charging the storage batteries.

The engine is arranged so as to form two units of three-cylinders each, and the three after cylinders, only, are connected to the compressed air tanks; when the reverse lever is thrown to the first notch off the center, either forward or backward, the cam shaft is shifted to such a position, that the cams operating the compressed air valves on these three cylinders will lift their exhaust valves once every revolution instead of every other revolution. The three forward cylinders always operate on gasoline, the shifting of the cam shaft having the effect of governing the direction of rotation of the engine only. With the lever in this position, the compressed air is admitted to the three after cylinders and the engine allowed to make two or three revolutions. The lever is then pushed on to the next notch, cutting out the compressed air valves and adjusting the cam to trip the valves in the regular four-cycle sequence. Means are also provided by which all the lower exhaust valves can be locked open, and all the lower inlet valves can be locked closed, instantaneously, by a single motion of the lever, thus converting the engine into a single-acting motor developing half power without any material decrease in economy. Furthermore, the two units can be unclutched, so that the three after cylinders can be operated alone as a three-cylinder single-acting unit, thus reducing the power developed to one-quarter the full power of the engine.

An increasingly large number of small pleasure craft are being fitted with gasoline motors for their propulsion; schooners and other trading vessels have also been fitted with auxiliary explosion engines to drive them during calms. The future developments of the marine internal combustion motor may be expected, however, to lie in the direction of the gas engine proper, using gas generated from coal, which may be obtained in any port.

In this case, a gas producer plant would replace the customary installation of boilers, taking up less space, diminishing the labor of stoking, and reducing the weight of machinery. Several vessels have already been built, notably by Thornycroft in England and Lewis Nixon in the United States; the latter builder having navigated gas-propelled torpedo boats across the Atlantic under their own power.

It has been estimated that the weight of a marine gas engine plant would not exceed seven-tenths that of a steam installation of equal power. This feature undoubtedly will be seized upon by naval architects, who will thus be able to devote a greater percentage of displacement to guns and protective armor.

The many auxiliary engines necessary on a warship or mail steamer are responsible for a very large proportion of the fuel consumption of those vessels. If gas-driven, these would be nearly as economical as the main engines. Again, the consumption of the main engines would vary but slightly with changes of speed, a necessary point on warships, which spend most of their time afloat at speeds of ten to thirteen knots, occasionally being called upon to make short bursts at top speed, when all idea of economy is thrown to the winds.

CHAPTER XXII.

TESTING.

252. Object of Testing. The ultimate object of testing a gas engine is to determine the economy with which it produces a given amount of power. The factory tests are usually limited to the performance of individual engines,—to determine the set of the governor relative to the proper speed of the engine; to ascertain if the igniter is properly timed, and if the valves open at the proper points in the cycle of operations; and to determine the correct amount of compression.

In the broadest sense of the term, however, testing is a scientific investigation intended to secure practical results highly important not only to the manufacturer, but also to the owner of the engine who has to pay the expense of its operation, and to those who need information respecting the capabilities of the machines.

253. Determination of Economy. The economy of steam engines as usually determined, relates to the weight of water consumed, to the quantity of coal used in making the steam, or to the number of heat units supplied; while in other forms of heat engine, it relates to the amount of gas, oil, or other fuel burned.

The heat consumption of internal combustion engines is found by ascertaining the total heat of combustion of the particular fuel used, as determined by a calorimeter test, and multiplying the result by the quantity of fuel consumed. In determining the total heat of combustion no deduction is made for the latent heat of the vapor of water in the products of combustion.

254. Standard Unit of Power. The unit of mechanical power which most satisfactorily expresses the power developed by an engine is the horse-power; therefore, the expressions of engine economy which are best adapted to meet all conditions, and for all classes of heat engines, are those involving the *indicated horse-power* based upon the number of thermal units consumed per hour.

255. Standard Unit of Fuel. A subsidiary form of expressing efficiency is that based on a standard coal unit. The term *standard coal* refers to a coal which imparts to steam 10,000 British Thermal Units for each pound of dry coal consumed. It is a coal which has a calorific value of 12,500 British Thermal Units, equivalent to an efficiency of 80 per cent. (10,000 B. T. U.) when used in a *standard boiler.*

256. Purpose of Test. In making a test, first ascertain its purpose or object,—whether it is made to determine the highest economy obtainable; the working economy and existing defects; or the effect of changes in normal conditions; and arrange the test accordingly.

257. Inspection of Engine. Examine the engine as to its general condition, and note any points of design, construction, or operation, which might have a special bearing on the object of the test.

Examine all the valves and valve seats, the piston and piston rings, and see that they are gas-tight.

See that all bearings and other working parts are in the best possible condition.

258. Measurement of Engine Dimensions. Measure the dimensions of the cylinder when it is hot and in working condi-

tion. Measure the clearance volume. This can be done approximately from the working drawings of the cylinder, but it is better to make it by actual test. For this purpose, set the engine carefully with the piston on its inner dead point. Take a measured quantity of water and pour it into the clearance space, until the whole space, including the ports, is completely filled. Measure the quantity of water left, and the difference will indicate the amount poured in. Measure the water by weight and determine the corresponding volume by calculation, making the proper allowance for its temperature. The clearance volume or ratio of clearance is the volume in cubic inches thus found divided by the volume of the piston displacement in cubic inches, the result being expressed as a decimal.

259. **Calibration of Instruments.** Calibrate all instruments and apparatus to be used in the test, and determine their accuracy and reliability by comparing them with recognized standards. Thermometers, pressure gauges, and indicator springs should be calibrated both before and after the tests. See Chapter XXIII.

260. **Duration of Test.** The length of time given to a test largely depends upon its character and the purpose for which it is made. For determining working economy, the duration of the test should cover a period equal to the number of hours per day during which the engine is usually operated.

In the case of an engine using producer gas, the length of time devoted to the test should be long enough to determine the amount of coal used in the gas producer. It should never be less than twenty-four hours, and preferably should extend over several days.

261. Commencement of Test. If the test is made to determine the performance of the engine under working conditions, it should begin at the time the engine is started on its regular work, and the observations continued until it shuts down for the day.

If the test is for determining the maximum economy of the engine, it should first be run a sufficient length of time so as to make all conditions normal and constant. Then begin the observations and continue them during the allotted period.

262. Measurement of Fuel. The methods of determining the fuel consumption depend upon the character of the fuel used.

If it be coal furnished to a gas producer, its name, size, per cent. of moisture, and quality should be ascertained, and the quantity supplied to the gas producer during a stated period, not less than twenty-four hours, should be carefully measured.

If it be oil, gasoline, alcohol, or distillate, it can be drawn from a tank, which may be refilled to the original level at the end of the test, and the amount, required for refilling, weighed, allowances being made for alterations in temperature; or in the case of a small engine, it can be drawn from a properly calibrated vertical pipe.

When gas is used, it should be measured by a suitable gas meter, and gas bags should be placed between the meter and the engine to keep the pressure as constant as possible.

The pressure and temperature of the gas, and the barometric pressure and temperature of the air, should be measured, and in determining the quantity of gas supplied as given by the reading of the meter, the temperature and pressure of the gas should be taken into account, as given in pars. 282, 283.

263. Number of Heat Units Used. The number of heat units used by the engine is found on multiplying the number

of pounds of coal or oil, or the cubic feet of gas supplied, by the total heat of combustion of the fuel as determined by a calorimeter, or from the data obtained by a chemical analysis. See paragraph 285.

264. **Measurement of Jacket Water.** The jacket-water can be measured by a water meter, or by a measuring tank, either before it enters the jacket, or after its discharge therefrom, as specified in paragraphs 287 and 292.

265. **Determination of Speed.** The speed of the engine or the number of revolutions of the crank shaft per minute, can be determined by counting the number of revolutions in two minutes, with the eye fixed on the second hand of a time piece; or by the use of some form of mechanical counter such as a tachometer or continuous recording engine register as described in paragraph 290.

In the case of an engine governed by the hit-or-miss method, the number of explosions per minute should be ascertained, when the engine is running under nearly maximum load, by counting the number of times the governor causes a miss in the number of explosions.

266. **Indicator Diagrams.** From the indicator diagrams taken during the test for the calculation of the mean effective pressure, etc., sample diagrams nearest to the mean should be appended to the report so as to give a complete record of the test.

267. **Standards of Economy and Efficiency.** The standand expression for engine economy is the indicated horsepower, or the brake horse-power, divided by the hourly consumpton of heat units.

The standard expression for efficiency is the thermal efficiency ratio or the proportion which the heat equivalent of the power developed bears to the total amount of heat actually consumed as determined by test. In this case, one horse-power per hour represents 1,980,000 foot-pounds of energy, and this divided by 778 foot pounds,—the mechanical equivalent of one British Thermal Unit, gives 2,545 for the numerator of the expression—

$$\frac{2{,}545}{\text{B. T. U. per H. P. per hour,}}$$

which expresses the thermal efficiency ratio.

268. Computations and Results. From the data obtained according to the rules prescribed in the foregoing paragraphs, there should be computed the following results:—

269. The Indicated Horse-Power.—I. H. P. This is expressed by the formula—

$$\text{I. H. P.} = \frac{E \times P \times A \times L}{33{,}000}$$

in which **E** is the number of explosions per minute; **P** the mean effective pressure in pounds per square inch; **A** the area of the piston in square inches; and **L** the length of the piston stroke in feet, and in which—

$$\frac{A \times L}{33{,}000}$$

is constant for a given engine. The constant 33,000 represents the number of pounds raised through one foot in one minute by one horse-power.

270. The Mean Effective Pressure.—M. E. P. The mean effective pressure is that obtained from the indicator diagram as follows:

Measure the area of the diagram with a planimeter, and divide the area in square inches by the length of the diagram to obtain the mean ordinate or the mean height of the diagram. Multiply the mean ordinate by the scale of the indicator spring and the product will be the mean effective pressure desired.

The more usual method is to measure off ten equidistant ordinates on the diagram, and multiply their average by the scale of the spring, the product being the mean effective pressure.

If the indicator is especially designed with a reduced piston for indicating gas engine pressures, the mean ordinate should be multiplied by twice the scale of the spring, unless the scale has been expressly marked for the reduced piston. See paragraph 288.

When indicator diagrams are not available, and the compression pressure is known, the mean effective pressure can be determined approximately under the following conditions:

In gas engines the compression pressures range from about 70 to 90 pounds per square inch, and the maximum pressures are about 3.5 times the compression pressures.

Therefore, if P_c represents the compression pressure, then for compression pressures up to 100 pounds per square inch, the—

$$\text{M. E. P.} = 2P_c - 0.01P_c^2;$$

so that, if $P_c = 70$ pounds per square inch, then

$$\text{M. E. P.} = 140 - 49 = 91 \text{ pounds per square inch.}$$

271. The Brake Horse-Power.—B. H. P. When this is determined by some form of dynamometer such as the Prony brake, it can be computed by the formula—

$$\text{B. H. P.} = \frac{W \times N \times L \times C}{33{,}000}$$

in which W is the net weight in pounds on the scales; N the

number of revolutions per minute; **L** the length of the lever arm from the center of the braked wheel to the knife edge of the brake, or the radius of the brake wheel in the case of a rope brake (continental engineers measure to the centre of the rope on either side); and **C** the circumference of the braked wheel.

As—

$$\frac{L \times C}{33{,}000}$$

is constant for a given Prony brake, if **L** be made 5.25 feet this constant becomes 0.001, and gives the simple formula—

$$B.\ H.\ P. = \frac{N \times W}{1{,}000}$$

272. Indicated Horse-Power or Brake Horse-Power converted into Heat. The number of foot-pounds of work done by one pound or one cubic foot of fuel divided by 778, the mechanical equivalent of one British Thermal Unit, will give the number of heat units desired.

273. Heat carried away by the Jacket Water. This is determined by measuring the amount of cooling water passed through the jacket equivalent to one pound or one cubic foot of fuel consumed, and calculating the amount of heat rejected, by multiplying that amount by the difference in the temperature of the water entering and leaving the jacket.

274. Heat rejected in the exhaust gases.—The sum of the heat converted into brake horse-power and the heat carried away by the jacket water, subtracted from the total heat supplied will give the total heat rejected or unused.

In order to determine the cost of each horse-power hour in

thermal units, the temperature and pressure of the gas consumed and the air supplied, should be reduced to standard conditions.

The most suitable standard for gas engine work is the equivalent volume of gas at normal atmospheric pressure (29.92 inches of mercury) at a temperature of 60° Fahr.

The gas consumed may be reduced to this standard by multiplying the reading of the volume by the factor given at the end of paragraph 286, or more conveniently by means of the following formula—

$$v = \frac{t}{p} \times \frac{v'p'}{t'}$$

in which v = volume of gas reduced to standard; $t = 461° + 60° = 521°$ Fahr., absolute standard temperature; $p = 29.92$ inches of mercury; v' = volume of gas registered by meter; p' = pressure of gas at meter measured by manometer in inches of mercury; and t' = absolute temperature of the gas.

Since t and p are constants—

$$v = 18.00 \frac{v'\,p'}{t'}$$

and as p' and t' are nearly constant during any given test—

$$v = E\,v'$$

in which—

$$E = 18.00 \frac{p'}{t'}$$

and p'=height of barometer + (0.073 × reading of water-manometer); and t'=temperature of gas at meter + 461°.

For example: Assuming the height of the barometer as 29.40; the reading of the manometer as 6 inches; the temperature of the gas as 80° Fahr.; and the volume of the gas reg-

istered at the meter as 350 cubic feet, we have for determining v—the equivalent volume of gas for standard conditions——

$$p' = 29.40 + (0.073 \times 6) = 29.84,$$
$$t' = 80° + 461° = 541°,$$

and
$$E = \frac{18.00 \times 29.84}{541} = 0.993$$

Then $v = 0.993 \times 350 = 347.5$ cubic feet.

275. **The Air Supplied** should be metered and reduced to standard conditions in a similar manner.

If the rate method is employed to ascertain the amount of gas consumed, the number of cubic feet for a ten-minute interval may be found by dividing the number of cubic feet, registered by one revolution of the small dial, by the time in seconds elapsed at the completion of that revolution, and multiplying the result by 6,000.

276. **Total B. T. U. per Hour.** The total amount of gas consumed in cubic feet, multiplied by its calorific value.

277. **B. T. U. per Brake Horse-power-Hour.** The total B. T. U. per hour divided by the brake horse-power.

278. **B. T. U. per Indicated Horse-power-Hour.** The total B. T. U. per hour divided by the indicated horse-power.

279. **Friction Horse-power.** The difference between the indicated horse-power and the brake horse-power.

280. **Thermal Efficiency.** The ratio of 2,545 B. T. U. to the B. T. U. per horse-power-hour.

281. **Mechanical Efficiency.** The ratio of the brake horse-power to the indicated horse-power.

CHAPTER XXIII.

INSTRUMENTS USED IN TESTING.

282. **Pressure Gauges.** Gauges for measuring the pressure of steam or other gases are made in a great variety of forms. Generally, the pressure of the gas causes a pointer to move around a graduated dial under the influence of the motion of a corrugated diaphragm, or as in the Bourdon gauge, in response to the tendency of a bent tube to straighten itself under the influence of pressure.

For pressures above that of the atmosphere, one of the most convenient and reliable instruments of this kind is the dead-weight testing apparatus. This consists of a vertical plunger working in a cylinder containing oil or glycerine, which transmits the pressure to the gauge. The plunger is surmounted by a circular stand on which weights may be placed so as to obtain any desired amount of pressure. The total weight, in pounds, on the plunger at any time, divided by the average area of the plunger and of the bushing which receives it, in square inches, gives the pressure in pounds per square inch.

Another reliable standard of comparison is the mercury gauge. This consists of a U-shaped glass tube about 30 inches long, with both arms filled with mercury. A stop-cock is usually placed between the gauge and the cylinder of the engine. When the stop-cock is open the pressure of the gas on the mercury in one arm of the tube forces it down so that it rises in the other arm. The difference in the heights of the two columns corresponds to the excess of pressure of the gas over that of the atmosphere. In using this instrument, great care should be

taken to see that it is correctly graduated with reference to the ever-varying zero point, the exact position of which depends upon the density of the mercury and volume of the tube as affected by the temperature. The mercury should be pure, and the proper correction should be made for any difference of temperature that may exist at the time of using, as compared with the temperature at which the instrument was graduated.

For pressures below the atmosphere, an air pump or some other means of producing a vacuum should be employed. It should always be compared, however, with a mercury gauge before using.

283. **Thermometers.** Standard thermometers are those which read 212° Fahr., when the whole of the stem up to that point is surrounded by steam escaping from boiling water at the normal barometric pressure of 29.92 inches of mercury; which read 32° Fahr., when the stem is completely immersed to that point in melting ice, and which have been tested and certified, between and beyond these two points of reference, by the proper authorities.

For temperatures between 212° and 400° Fahr., comparisons should be made with the temperatures given in Regnault's Steam Tables, by placing the thermometer in a well of mercury surrounded by saturated steam under sufficient pressure to give the desired temperature. The pressure should be accurately determined by some one of the methods already described with reference to gauges.

284. **Pyrometers.** These instruments are generally used for measuring temperatures higher than 648° Fahr.,—the boiling

point of mercury. They are made in a great variety of forms, usually based on the general tendency of metals to expand under the influence of an increase in temperature.

Perhaps the most useful instrument of this kind is that devised by Le Chatelier. It consists of two pieces of wire of but slightly different composition, which are enclosed in a long tube of porcelain or fire clay. These wires are platinum and an alloy of 90 per cent. platinum and 10 per cent. rhodium. The action of heat sets up electricity in the wires, forming a thermocouple, and the electric current produced by an increase in temperature is measured by a galvanometer. It measures, readily and accurately, temperatures as high as 3,000° Fahr.

When a pyrometer is used, it should be compared with a mercurial thermometer within its range, and if greater accuracy is desired at very high temperatures, it should be compared with an air thermometer, which is the accepted ultimate standard of reference in all high temperature measurements.

285. Calorimeters. These consist of various forms of apparatus used for the purpose of ascertaining the calorific values of substances used for fuel. The rational method of determining the total heat of combustion of a substance is to burn it in an atmosphere of pure oxygen gas.

For this purpose, the Barrus and Mahler calorimeters are among the most reliable for solid fuel or oil, and the Junker calorimeter for gases.

The Barrus calorimeter is especially applicable to the testing of coal. As shown by *Fig.* 139, it consists of a glass beaker, A, 5 inches in diameter and 11 inches high. The combustion chamber is of special form, consisting of a glass bell, B, having a notched rib around the lower edge and a bead just above the

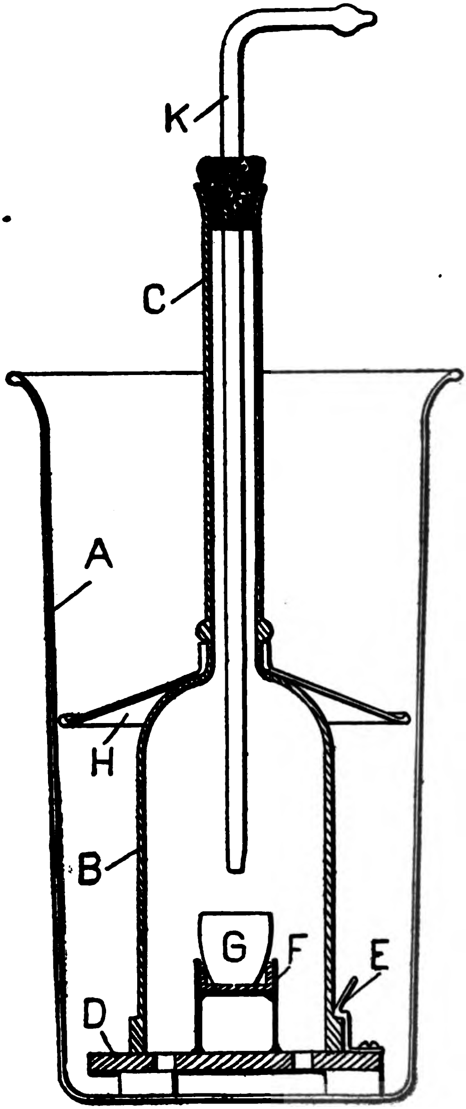


Fig. 189.—Barrus Coal Calorimeter.
(Paragraph 285)

dome, with a tube, C, projecting a considerable distance above the upper end. The bell is $2\frac{1}{2}$ inches inside diameter, $5\frac{1}{2}$ inches high, and the tube, C, $\frac{5}{8}$ inches inside diameter, extending to a height of 9 inches beyond the bell. The base, D, consists of a circular piece of brass, 4 inches in diameter, and is provided with three clips, E, fastened on the upper side for the purpose of holding down the combustion chamber. A cup, F, for holding the platinum crucible, G, in which the coal is burned, is attached to the center of the plate. A hood, H, made of wire gauze is attached to the upper end of the bell beneath the bead, for the purpose of intercepting the rising bubbles of gas and thus retarding their escape from the water. The top of the tube, C, is fitted with a cork through which a small glass tube, K, carries the oxygen to the lower part of the combustion chamber.

The tube, K, is movable up and down, so as to permit of its being adjusted to the proper distance from the burning coal, and also to some extent sideways, so that the current of oxygen may be directed to any part of the crucible.

To make a test with this instrument, the following named apparatus is required: A tank of oxygen, scales for weighing water, delicate balances for weighing coal, an accurate thermometer graduated to tenths of a degree Fahr., for taking the temperature of the water, and a thermometer to give the temperature of the atmosphere.

Fig. 140, shows the general arrangement of Junker's calorimeter. The apparatus is designed for determining the number of heat units in a given volume of gas, such as a cubic foot or a cubic meter. It consists of a meter, A, a pressure regulator, B, and a calorimeter proper, C. The gas enters the meter at *e*, and passes through the pressure regulator to the calorimeter proper, where it burns at the burner, *f*. The products of com-

bustion rise to the top of the calorimeter and enter a double row of pipes which are surrounded by circulating water, and after passing down through the pipes they issue at the flue, *g*.

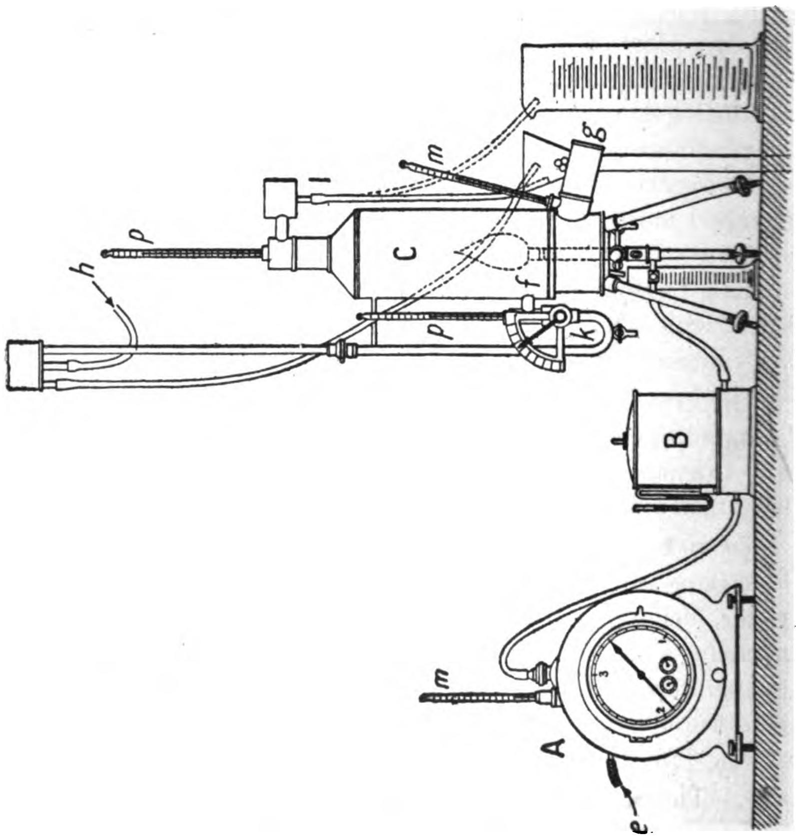


Fig. 140.—Junker's Calorimeter.
(Paragraph 285)

The water enters at *h*, and passing through the regulating cock, *k*, enters the calorimeter; circulates around the tubes, and issuing at *l*, flows into the measuring glass. The thermome-

ters, *mm* and *pp*, register the temperature of the gas and water respectively, upon entering and leaving the apparatus.

The heating value of the gas is computed by the formula:

$$H = \frac{(t - t') w}{v}$$

in which t is the average temperature of the entering water; t′ the average temperature of the issuing water; w the weight of the cooling water in pounds; and v the number of cubic feet of gas reduced to standard conditions of temperature and pressure.

This value will be too large, however, as the water formed by the combustion of hydrocarbons in a gas is not condensed, and therefore passes off with its latent heat of vaporization into the exhaust.

The effective heat value of the gas will, therefore, be found by multiplying the weight of condensed water in pounds by 966, and dividing the product by the number of cubic feet of gas, and subtracting the result from the computed value of H.

286. Gas Meters. These instruments are used for measuring the gas supplied to engines or calorimeters. They are of two kinds,—*wet meters* and *dry meters*. The former, on account of the various difficulties connected with their use, the chief of which is the liability to freezing in cold weather, have been almost entirely superseded by the latter.

The dry meter consists of a rectangular box of tin-plate, divided into two main compartments by a horizontal partition. The lower compartment is still further subdivided into two equal parts by a vertical partition. The measuring device consists of two bellows, one in each division of the lower com-

partment. Each set of bellows consists of a circular metal disc to the circumference of which is fastened one edge of a leather diaphragm, the other edge of which is fastened to the central partition. The whole arrangement forms a gas-tight space. The pressure of the gas as it is admitted, first into the space inside, and then into the spaces outside of the bellows, opens and closes them alternately, thus furnishing the motion which operates the inlet and outlet valves in such a way that gas cannot pass simultaneously into and out of any one of the spaces. This motion also works the train of gearing which records the amount of gas passed through the meter, and the action of the mechanism also controls the extent to which a bellows can open and close, so that a definite volume of gas passes into and out of the meter each time it is filled and emptied.

When a meter is used in a gas engine test, it should be calibrated by comparing its readings with the displacement of a gasometer of known volume; by comparing it with a meter of known error; or by passing air through the meter from a tank containing air under pressure. In the latter case, the temperature and pressure of the air from the tank should be observed, both at the tank and the meter, at regular or equal intervals of time during the progress of the comparison.

The volume of air passing through the meter is computed from the volume of the tank and the observed temperatures and pressures, and the volume thus ascertained should be reduced to its equivalent at a given temperature and pressure, and corrected for the effect of moisture in the gas, which is, as a rule, at or near the point of saturation.

The most suitable standard for gas engine work is the equivalent volume of the gas when saturated with moisture at the normal pressure of the atmosphere at a temperature of 60° Fahr.

The reading of the volume containing moist gas at any other temperature may be reduced to this standard by multiplying it by the factor,—

$$\frac{459.4 + 60}{459.4 + t} \times \frac{b - (29.92 - S)}{29.4}$$

in which **b**, is the reading of the barometer in inches at 32° Fahr.; **t**, the temperature of the gas at the meter in degrees Fahr., and **S**, the vacuum in inches of mercury corresponding to the temperature **t**, obtained from the steam tables.

287. Water Meters. These devices are used for measuring and automatically recording the quantity of water flowing through pipes. They are of three classes,—the *positive meter* which measures the actual volume of water passing through the pipe with which it is connected; the *inferential meter* which measures some element or factor of the flow, usually the velocity; and the *proportional meter* which measures a fractional part of the flow, thus enabling the use of a relatively small meter which can be attached to a by-pass on the main pipe. In all of them, the registering mechanisms consist of an arrangement of cogwheels by which the movement of the water is transmitted to a series of graduated dials.

When used for testing purposes, they should be carefully calibrated by some reliable method.

288. Indicators. Gas engine indicators practically operate on the same principle as those used on steam engines, but are

made much stronger so as to indicate the higher pressures successfully. They are equipped with a smaller piston and a stronger spring, and the pencil arm is made much stouter so as to withstand the sudden shock developed in a gas engine cylinder at the moment of explosion.

When used in a test, the indicator springs should be calibrated by compressed air, or compressed carbonic acid gas, great care being taken to maintain temperature conditions similar to those which exist during a test. If it is desired that the springs should be calibrated under constant pressure, the whole range of pressures through which the indicator acts should be covered as follows: first, gradually increase the pressure from the lowest to the highest point, and then gradually reduce it from the highest to the lowest point and take the mean of the results. The calibration should be made for at least five points,—two for the pressures corresponding to the maximum and minimum pressures, and three for pressures at intermediate, equally distant points.

The most reliable standards of comparison are the deadweight testing apparatus and the mercury column. A steam gauge, the accuracy of which has been previously determined by comparison with either of these standards, may also be satisfactorily used.

Fig. 141, shows a part sectional view of the American-Thompson indicator with the new detent motion.

In working out the mean effective pressure from the indicator diagrams, the correct scale of the spring will be the average based on its calibration, and it can be ascertained in the following manner:

When the scale of the spring varies from the nominal scale uniformly, the arithmetical mean of the scales obtained at the

different pressures tried, will be sufficiently accurate. On the other hand, when the scale varies considerably at the different

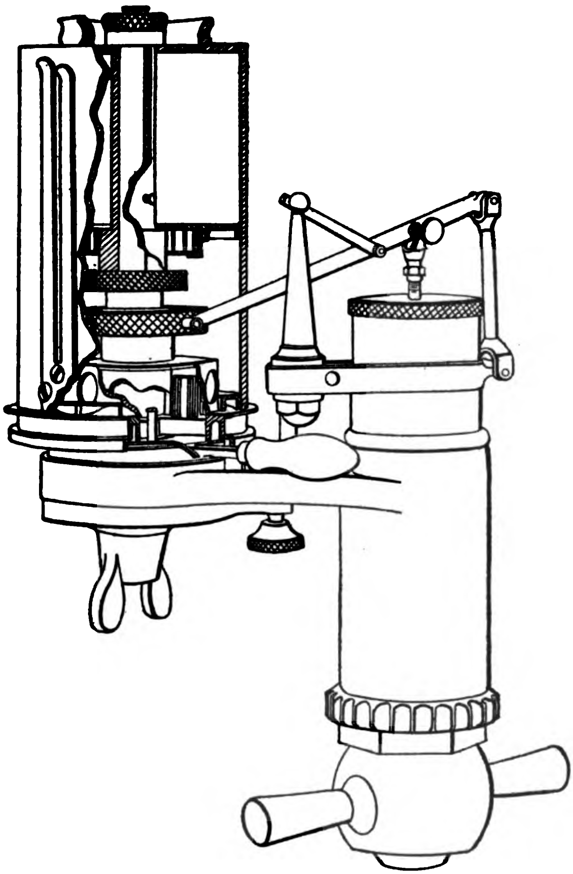


FIG. 141.—AMERICAN THOMPSON INDICATOR.
(Paragraph 288)

points, absolute accuracy can be attained by the following method: select a sample diagram and divide it into a number of

parts by drawing lines parallel to the atmospheric line. The number of lines should equal and correspond to the number of points at which the calibration is made. Take the mean scale of the spring for each division and multiply it by the area of the diagram lying between two contiguous lines. Add all the products together and divide by the area of the whole diagram, the result will be the average scale required.

289. **Planimeters.** These instruments are used for automatically measuring the areas of irregular figures on a plane surface. They are made in a number of forms, usually consisting of two arms hinged at one end, the outer end of one being a pointed support, and that of the other a pencil. A graduated roller is attached to the pencil arm, with its axis parallel to that of the arm. To obtain the area of an indicator diagram, the pointed support is fixed at some point outside of the diagram, and the instrument is moved bodily about it with the pencil or tracer following the bounding line of the figure. When the circuit is completed by the pencil, the area of the figure will be indicated by the reading of the roller.

290. **Revolution Counters and Tachometers.** These devices are used for determining the speed of an engine, by automatically counting and recording the number of revolutions of the crank shaft. Their use is absolutely necessary when the speed of an engine exceeds 250 revolutions per minute. In a test, the use of a continuously recording counter is necessary to give the most reliable results.

291. **Brakes and Dynamometers.** These consist of various forms of apparatus used for determining the brake horse-power of an engine.

The most familiar form is the Prony brake, consisting of a friction band which may be placed around the fly wheel or around the crank shaft, and attached to a lever bearing upon the platform of a weighing scale, as shown in *Fig.* 142. A brake used for testing purposes should be self-adjusting to a certain extent, so as to maintain, automatically, a constant resistance at the rim of the wheel. For comparatively small engines, various forms of rope brakes, such as the one shown in *Fig.* 143,

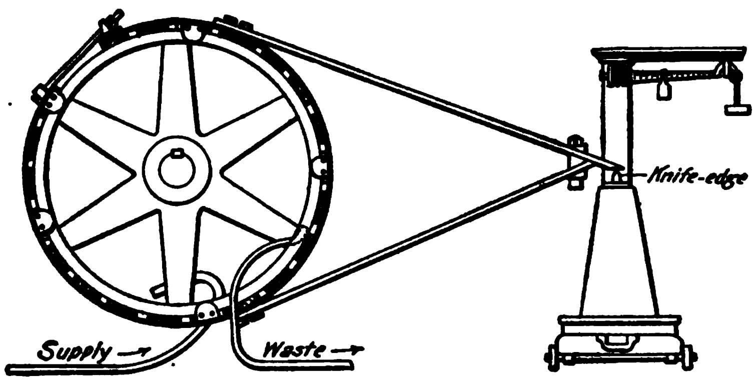


FIG. 142.—PRONY BRAKE.
(Paragraph 291)

satisfy this requirement very well. In such cases, a specific weight is hung to one end of the rope and a spring scale to the other end. The wheel should be provided with interior flanges, holding water for keeping the rim cool. For very high speeds, some form of water-friction brake should be employed, as they have the advantage of being self-cooling. They have been successfully used at speeds of over 20,000 revolutions per minute.

292. Tanks. In some cases, tanks may be used more conveniently than meters for measuring the jacket-water. A simple

apparatus of this kind consists of a small hogshead with a capacity of about 6,000 pounds of water per hour, connected to the suction pipe, and an ordinary oil barrel, the latter being mounted on a platform-scale supported on one side by the hogshead and on the other side by a suitable staging. The barrel is filled by means of a cold-water pipe leading from the source of

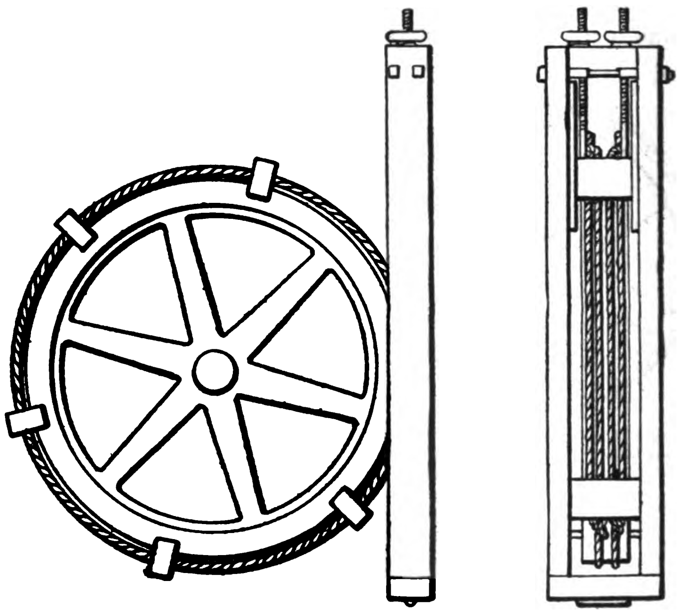


FIG. 143.—ROPE BRAKE.
(Paragraph 291)

supply. For pressures not less than 25 pounds to the square inch, this should be a 1½ inch pipe. The outlet valve should be attached to the side and close to the bottom of the barrel, and should be at least 2½ inches in diameter so as to allow quick emptying. Where large quantities of water are required, the barrel can be replaced by a hogshead, and two additional hogs-

heads can be joined together for the lower reservoir. When the weighing hogshead is thus supplied through a 2½ inch valve under a pressure of 25 pounds and emptied through a 5-inch valve, the capacity reached is 15,000 pounds of water per hour. For still larger capacities, rectangular tanks may be used with the weighing tank so arranged that the ends overhang the scales and the reservoir below, and the outlet valve, consisting of a flap-valve, covers an opening in the bottom 6 or 8 inches square. The rectangular tank system can be employed for any size of stationary engine met with in ordinary practice.

When very large quantities of water have to be measured, or in some cases, relatively small quantities, the orifice method is the one that can be used most satisfactorily. In such cases, the average head of water on the orifice must be determined, and it is also important that proper means should be taken for calibrating the discharge of the orifice under the conditions of actual use.

In measuring jacket-water, or any supply under pressure, which has a temperature over 212° Fahr., the water should be first cooled, as may be done by discharging it into a tank of cold water previously weighed, or by passing it through a coil of piping submerged in colder running water, thus preventing the loss by evaporation which attends the discharge of hot water into the open air.

CHAPTER XXIV.

NATURE AND USE OF LUBRICANTS.

293. **Lubricants for Various Purposes.** One of the most important considerations in connection with the operation of an engine, of any power, relates to the proper lubrication of its moving parts. As is perfectly evident on reflection, it is necessary that all such parts should be supplied with oil or lubricating grease, but it is also a fact, not so well understood, that different kinds of lubricant are necessary for different kinds of mechanisms.

294. **Lubricants for Gas Engine Cylinders.** The piston is the most important part of an engine. Upon it is expended the force generated by the explosion, and, upon its tightness or freedom from leakage, depends the development of power and the maintenance of proper compression, so necessary for economical running.

The piston usually travels at great velocity, and is subject to high temperatures, which militate against efficient lubrication. As it moves to and fro it presses against the cylinder walls, exposing them to the burning gases, thus rendering the coating of oil, which is used to lessen friction, liable to be volatilized or carbonized.

The oils for internal lubrication must be carefully chosen, as the temperatures within the cylinder of a gas engine are far higher than those experienced with a steam engine cylinder. Regard must be paid to their quality, a perfectly pure mineral oil being necessary, entirely free from admixture with animal or vegetable matter, and possessing a flash point as high as pos-

sible. The specific gravity of such an oil, when of the highest quality, will lie between .885 and .890 at 62° Fahr.; it will begin to evaporate at about 360° Fahr., and have a flash point of well over 500°, probably 520°, while its burning point lies between 625° and 645° Fahr. This oil thickens rapidly in cool weather, solidifying at about 40° Fahr. It has a viscosity of between 11.5 and 12.5, as compared with water, at a temperature of 140° Fahr.

It is perfectly practicable to use an oil, having the flash point mentioned, in a gas engine cylinder, whose temperature at explosion is very much higher, because, with a properly adjusted water circulation, the burning and carbonization of the oil is constantly prevented. The heat-absorbing action of the jacket-water is also efficient in retaining at the required point the viscosity of the oil—that is to say, the quality of dripping at a certain ascertained rate through a narrow aperture under pressure. This quality virtually refers to the thinness of the oil.

It is also necessary to have an oil with a low freezing point, as a very necessary insurance against congealing, and consequent delay and inconvenience in starting the engine. Its resistance to heat should also be placed at such a figure that it will not become unusually thin, as will some qualities of oil, its viscosity being maintained at the desired point.

A method of forced cylinder lubrication is illustrated in *Fig.* 144, showing how the oil is supplied to the piston and cylinder walls, at another part of the stroke to the piston pin, and at another time to the crank pin bearing, all through the same supply.

295. Organic Oils. For lubricating machinery as apart from cylinders, it is customary to use organic oils of animal or vegetable origin, on account of the greater *body* or viscosity

which they possess, as compared with mineral oils. To make these oils cheaper, they are admixed with a large proportion of mineral lubricant. While such oils serve admirably for those parts of a gas engine which correspond to the running gear of a steam engine, they are entirely inadmissible about a fast running gasoline motor, where the running parts are enclosed in a heated crank-case.

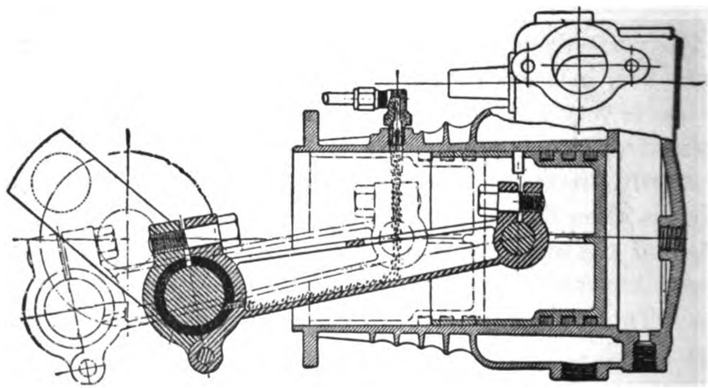


FIG. 144.—HORIZONTAL CYLINDER OILED BY FORCE-FEED OIL DISTRIBUTER. The piston is oiled when passing under oil port, as shown by the dotted outline. The connecting rod is longitudinally grooved on the upper surface, so as to carry oil to the bearings. (Paragraph 294.)

Vegetable oils readily carbonize at high temperatures, forming a thick rusty colored deposit, which often sets hard, choking up ports and passages, creating much friction, and damaging the piston and its rings. A lubricant of animal origin, while not so liable to form carbon deposits, is apt to decompose into fatty acids, corroding the working parts.

With a good cylinder oil, the slight deposit left is usually of a blue grey or slaty color, and is harmless.

296. Use of Graphite as a Lubricant. Many authorities strongly recommend the use of powdered or flaked graphite, in the cylinders of explosive engines, for the reason that this substance is one of the most efficient of solid lubricants, especially at high temperatures. It has been found especially useful in some steam engine cylinders, and in general on those bearings and moving parts liable to become overheated. According to several well-known authorities, it is well adapted for use under both light and heavy pressures when mixed with certain oils. It is also especially valuable in preventing abrasion and cutting under heavy loads at low velocities.

In using graphite as a lubricant, it is positively essential to remember one thing: It is, as said, very useful for certain purposes, when mixed with some liquid oil lubricants. However, it is impossible to use it in connection with oils that are to be filtered through the small orifices of constant feed oil cups, as on the cylinders and bearings of engines. The reason for this is that it will not flow through small holes, even when mixed with very thin oil; and the very cooling of a bearing will cause the graphite, mixed with oil, to clog up the oil hole to an extent that may not be remedied by the re-heating of the bearing, after the stoppage of the lubricant. On the same account, it is essential that the oil conduit to any moving part be ascertained to be of suitable shape and proportions before the use of any solid lubricant is attempted.

297. Requirements in Gas Engine Lubrication. It is essential in a gas engine cylinder that the oil should be constantly supplied at a uniform rate which is capable of regulation; and for the purpose of properly meeting this requirement a number of different kinds of dripping and filtering oil cups have been devised and put into practical use.

As has been repeatedly pointed out by gas engine authorities, the apparently long period spent in finally perfecting the motor was due almost entirely to the fact that the subject of proper lubrication was not fully understood. With the ordinary oils, it was impossible to obtain anything like a satisfactory

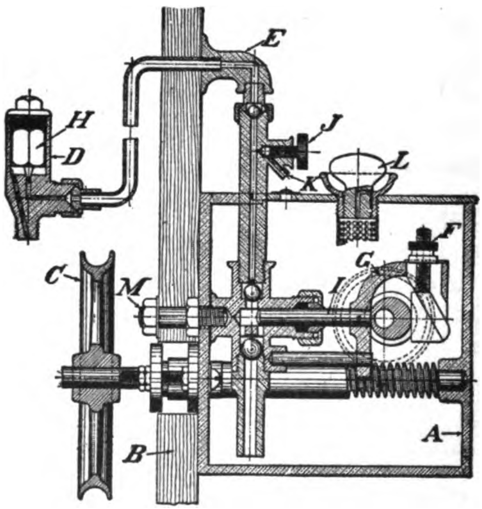


Fig. 145.—Section through a Type of Power-driven Oil Pump.

A, oil reservoir; B, dashboard of car; C, pulley driven by belt from engine shaft; D, gravity valve on distributor; E, outlet elbow; F, set screw to regulate stroke of plunger, I; G, plunger bracket bearing against eccentric, which is on the gear operated by worm, or endless screw, on the shaft or pulley, C; H, weight of gravity valve, D for holding outlet port normally closed, and rising under pressure of oil from pump; I, plunger of pump drawing oil from reservoir, A, through ball valve, and expelling it through ball valve to outlet, E; J, test cap for testing flow of oil; K, oil outlet for test cap; L, filling plug and strainer; M, stud bolt for securing machine to dashboard.

(Paragraph 298)

speed and power efficiency, and only when the superior properties of mineral oils were better understood was the present high degree of perfection in any sense obtainable. Even to the present day the question of proper lubricants for gas engines is most essential, and, as has been pertinently remarked, "the saving of

a few cents per gallon in purchasing a cheaper grade of oil for this purpose is the most expensive kind of economy imaginable."

298. Oil Pumps and Circulation. With the use of high-speed gasoline engines, it has been found necessary to use a forced circulation of the oil in order completely to lubricate the

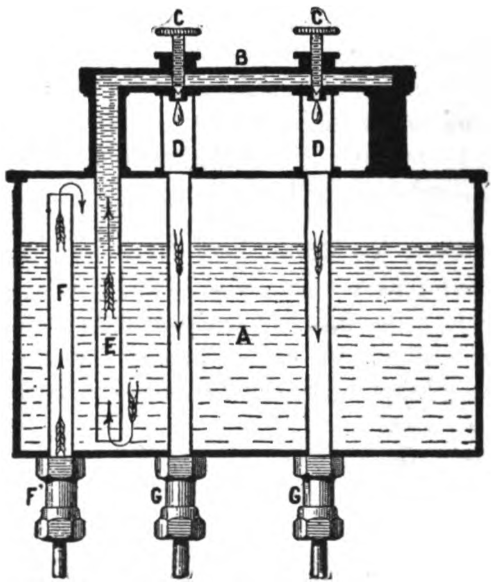


FIG. 146.—TYPICAL FORCE-FEED LUBRICATOR, OPERATING BY AIR OR GAS PRESSURE, INSTEAD OF A PUMP.

The parts are: A, oil reservoir; B, distributing pipe; C, C, valve screws for regulating flow of oil to parts, through leaders, D and D; E, standpipe through which oil is forced by air pressure; F, standpipe admitting gas from crank case of Engine; F', union for pipe from crank case; G, G, unions for pipes to various parts of the machinery.

(Paragraph 298)

interior of the cylinder. The most usual method with high-powered multiple-cylinder engines is to employ a positively-geared pump to force the oil through adjustable sight-feed conduits to the various moving parts. Such pumps, operating in ratio to the speed of the engine, of course supply lubricant

more rapidly as the number of revolutions increases, and slow down as it decreases. Thus, a perfect supply is maintained, as required, on the one hand, and flooding is prevented on the other. There are several efficient types of oil pump on the market, all working on the same principle of forcing the oil to the moving parts in such volume as may be determined by the adjustment. One or two inventors have produced devices of this kind operated by compressed air forcing the oil out of a tank, the degree of compression being determined by the speed of the engine operating the air pump. A pump, illustrating the first method, is shown in *Fig.* 145, and a force feed reservoir under air pressure in *Fig.* 146.

299. **Lubricants for Motor Cars.** In choosing lubricants for any of the moving parts of a self-propelled road vehicle it is especially essential to see that the quality of resisting temperatures, both high and low, without change of useful consistency, should be present. An oil that will congeal at ordinary low temperatures, or become thin at ordinary high temperatures, is, of course, entirely unsuitable for this purpose. Furthermore, the quality of flowing freely from well-adjusted oil cups should be assured, since the high speed of automobile engines, engendering a constant vibration affecting more or less the adjustment, requires that the oil supplied should be a subject of constant solicitude. To state the matter in a few words, all competent authorities seem to agree that the conditions of automobile operation require the use of mineral oils on all moving parts, and the avoidance of any mixture with animal or vegetable oils, which, although frequently used in stationary engines, cannot but result in inconvenience, not to say disaster, in automobile practice.

Since most manufacturers of motors and vehicles furnish moderately full directions for dealing with the question of lu-

brication, it will hardly be necessary to add more to the principles already laid down. If the automobile driver constantly bears in mind the fact that an oil suitable for one portion of his machinery is not of necessity suitable for every other, and will observe the conditions essential to maintaining the oil used at its proper consistency, he will have little trouble upon this score.

300. **Points on Lubrication of Motor Vehicles.** The first important consideration involved in preparing a carriage for a run is to see that the moving parts are properly lubricated. Every carriage or motor is sold with directions for providing for this necessity, the rate of oil consumption and the quantity being specifically designated. The principal parts which it is particularly necessary to keep thoroughly oiled are the cylinder pistons, the bearings of the crank shafts and fly-wheels, the differential gear drum and the change speed gearing.

Since on most well-built motors and carriages the moving parts are supplied with lubricating oil by means of sight feed oil cups, of familiar design, it is necessary to do no more than to see that the required level of oil is always maintained. As specified by many motor carriage authorities, it is desirable to thoroughly examine and replenish the oil supply in the adjustable feed cups at the end of about every thirty miles of run. Another consideration of importance in this particular is that before replenishing the supply of oil to such parts as the crank case or the differential gear, the old lubricant should be thoroughly evacuated by means of the vent cocks supplied in each case. The reason for this is that, after a run of from twenty to thirty miles, the oil in the moving parts is apt to be largely contaminated with dust and other impurities, which tend to interfere with its usefulness as a lubricant.

CHAPTER XXV.

HINTS ON MANAGEMENT AND SUGGESTIONS FOR EMERGENCIES.

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301. **Fire Risks and Precautions—Gasoline.** The greatest care is necessary in dealing with the highly inflammable fuels used in internal combustion engines. Gasoline or benzine must never be opened or poured from one vessel to another while a lamp or fire is burning in the same or a neighboring room. If such work cannot be done by daylight alone, *incandescent electric lights* only should be employed. Kerosene must be handled with almost equal care, should be kept in stoppered cans, and only opened under the same conditions as gasoline. Should a little of either fuel fall on the floor, it must be instantly wiped up. A box of fine *dry* sand, big enough to hold a reasonably large scoop, should be in every gasoline engine room, for fire extinguishing purposes, or for absorbing drippings. Keep the box full, the scoop in it, and the lid closed. Water will only increase a fire occasioned by petroleum products, the flames spreading on the water. On the other hand, alcohol flames are extinguished by water.

302. **Fire Risks and Precautions—Gas.** Before opening any part of a gas engine, it is necessary to go around and examine all connections and see that they are shut tight. After closing everything it is advisable to run the engine around a time or two by hand or by compressed air, to exhaust any gas or vapor remaining within the cylinder, before taking off the covers. Have everything opened and well ventilated before

bringing a light near. If possible, use only a portable incandescent lamp attached to a flexible cable. Do not seek leaks with a naked flame.

303. **Ventilation.** Owing to the practical impossibility of keeping gas-mains and connections free from some leakage, it is necessary to have a well-ventilated engine room, wherever internal combustion engines are installed. For this reason, wherever possible, they should not be placed in a cellar. Suction fans should be employed in preference to blowers, so that the foul air may be drawn out, not forced into corners and crevices.

304. **Leakage.** Leaks around mains, etc., are easily detected by means of a lather of soft soap and water, the bubbles indicating the leak. In screwed iron pipes, if previously pulled up good and tight, a leak may generally be stopped by caulking lead wire into the threads. Leaks on lead pipes should be soldered, the gas being previously shut off.

305. **General Care of Engine.** All bright and polished parts should be kept clean and shining; painted and non-polished parts should not be allowed to accumulate dust, oily dirt, etc. When the engine is standing, and especially when overhauling, little plugs of clean teased waste should be used to prevent the entrance of dirt into oil holes, etc. Some strands of spun yarn or sennet soaked in tallow, should be laid each side of the crank pin brasses and between the crank webs and main bearings, to prevent grit from getting into those important journals. Never use emery on brass or lacquered work, a good metal-polishing paste or whiting will give a much better result and will not scratch. Always scour rods, etc., one way, a connecting rod always looks better when polished around than lengthwise.

306. Overhaul of Engine. No stated time can be set as the proper interval to elapse between overhauls. So much depends upon the quality of the fuel used and the nature of the lubricant. Two or three months is the *maximum* time, in general cases, where efficiency is desired.

307. Tightness of Cylinder. It is necessary to keep in good order those parts upon which depend the tightness of the engine, such as the cylinder and piston, the cover and valve joints, the ignition apparatus and all valves. Leakage causes loss of power and defective compression, with consequent waste of fuel.

308. Care of Cylinder. The cylinder bore and piston surfaces become coated with a glaze or hard skin through rubbing on each other. This glaze prevents wear and care should be taken that it is not abraded: to that end neither the cylinder nor the piston should be polished with emery, brick dust or other abrasive, but should be scraped clean of oil, charred matter and dirt by means of *copper* or *bronze* tools, and *washed* clean with petroleum.

309. Piston. A solid piston, with Ramsbottom or snap rings, is regarded as superior to one of the built-up pattern; the bolt-heads securing the junk-ring or follower of the latter type frequently retaining sufficient heat to cause premature ignition. With the first type, at least four rings should be fitted. A long piston is indispensable to a gas engine, as it has to serve as cross-head guide; a short one tends to tilt in the bore wearing it oval.

310. Piston Rings. They should be taken out and cleaned each time the engine is opened. If set fast, they may be loosened by hand with the aid of a little kerosene. The ring next the cylinder head will first require renewal, but Ramsbottom

rings can generally be expanded a little by peening. In setting them out, the ring should be hammered all around its inner circumference, the blows slightly heavier opposite the split; care being taken that each blow falls in the middle of the width, and at equal distances apart, to avoid distortion. A thin ring is superior to a thick one, and the splits should be V or Z-shaped instead of straight across, all breaking joints with one another.

311. **Joints.** The importance of tight joints is apparent; to secure this desirable point, in many engines the valve boxes, etc., have ground joints, being fitted "metal to metal," either without any joint, or at most with a thin luting of red-lead. Otherwise, joints should be made of asbestos, either millboard or cloth with wire gauze insertion. These joints should first be cut out exactly to size, using a carpenter's chisel or gouge, and saddlers' punches for the bolt holes. Next they should be soaked in water to soften them, the cleaned surface on the cylinder being well oiled meanwhile with ordinary boiled or raw linseed oil, to make the joint adhere. When the joint is placed on the studs, its outer face should be well painted with graphite and water, a plentiful dusting with dry graphite being desirable. The cover or head is then put on and tightened up, the nuts being gone around and followed up as the engine warms. The oil makes the joint adhere to the cylinder, while the graphite lets the cover leave it without tearing. All projections of the joint, inside the cylinder, should be cut away as they may burn off; it is judicious to cut the joint well clear of the cylinder bore for this reason. All oil should be wiped off the studs before putting on the nuts, as this may gum and hold the nuts fast.

312. **Valves.** These are largely made of steel, although some makers of large engines use cast iron. They should be kept in first class order from motives of economy of fuel, an in-

spection being made monthly even if they do not betray signs of rapid wear. Especial attention should be given to the exhaust valve, on account of the high temperatures in which it works. Care should be taken that no valves get dirty, rusty or overheated; their stems should be gauged to see that they are not bent, also that they do not fit their seats too tightly, as they may expand and stick when working. If the stem leaks, the seat should be reamed out and bushed or a larger stem fitted. If the valve springs weaken through long use or overheating, they should at once be replaced, to save loss of compression, etc. As it is necessary that the new ones should be of the same strength as those originally fitted, spare springs should be obtained from the makers.

313. Regrinding Valves. The process consists in rotating the valve upon its seat, by means of a brace or screw-driver, an abrasive agent being smeared upon the parts in contact. This wears valve and seat to smooth polished surfaces, and should be prolonged until all specks and marks are removed. Ground glass is a much better material than emery, cutting much cleaner; brick-dust or pumice powder should be used as a finisher. It is necessary to rotate the valve first one way and then the other to grind it evenly. Deep scores require to be removed by file or scraper, or the seat and valve may require machining.

314. Valve Gear.. Take notice of all marks on cog-wheels, valves, etc., when stripping the engine, else mistakes will occur in replacing. In the gearing driving the two-to-one shaft, it will generally be found that the pinion has a dotted tooth, marks or figures being placed on two teeth of the gear-wheel; in setting up, put the one marked tooth between the two marked

teeth on the other wheel. With multi-cylinder engines, notice must be taken of the setting of each separate valve gear.

315. **Governor and Valve Gearing.** These parts should be carefully and regularly oiled, without excess of lubricant; in order to prevent clogging or gumming, leading to sluggish action, an occasional dose of kerosene should be given to all parts, especially the small pins and links about the governor. Where small capped oil cups are fitted on a shaft or inertia governor, they should be filled, at the commencement of each run, with vaseline or mica grease.

316. **Adjustment of Brasses.** In view of the shocks to which they are subjected, the various parts being likely to jar loose, all bearing-bolts should be set up good and tight; unless the engine is very small, a hammer should always be used on the spanners. The various bearings should be as tight as possible, as back-lash or lost motion tends to make a heavy knock or pound in a gas engine. Discretion must, however, be observed in making adjustments, as the piston pin or cross-head expands considerably under the high cylinder temperatures, and the connecting rod big-end should be always movable with a bar.

317 **Nuts Set Fast.** Cylinder cover nuts and those on the piston-rod not infrequently are difficult to remove; they may be loosened by the following means. A piece of iron bent hexagon like a ring spanner, which fits the nuts loosely, is made red hot and placed around the nut. This will generally expand them sufficiently to loosen them. Always have a ring or box-spanner for these nuts; an open wrench will often pull the corners off and deface the nut. The use of a caulking tool is unworkmanlike.

318. Amount of Cooling Water. The tanks should be capable of containing 45 to 60 gallons of water per indicated horse-power, the inlet temperatures being about 60° Fahr., and the outlet 140° Fahr. Larger allowances should be made with a heated engine room, or in warm climates. The hourly flow of water through the jacket should be 5 to 6 gallons per horse-power.

319. Leaks in Water Jacket. These may be stopped by means of a rust-making solution, say ½ lb. sal-ammoniac to 1 gallon water, letting it stand in the jacket all night. Blow-holes may be filled with a cement made of cast iron borings, sal-ammoniac and sulphur, made into a paste with fresh water.

320. Non-Freezing Solution. When laying off an engine during cold weather, it is advisable to fill the jackets (and radiator of a motor vehicle) with a non-freezing solution. A saturated solution of chloride of lime ($Ca\ Cl_2$) at the rate of 10 lbs. chloride to one bucketful of boiling water, is recommended. Let the brine settle, and strain it through a cloth before pouring into the jacket.

321. Quality of Cooling Water. The best for the purpose is rain water, collected from the roofs of the buildings and strained. City water usually contains lime salts, which form incrustations within the water jacket, like the scale in a boiler or kettle. This incrustation is harmful; being a non-conductor, it raises the temperature of the cylinder to the detriment of its lubrication, and also tends to choke the passages. River water is apt to contain mud, dangerous for the same reasons.

322. Treatment of Water. Conveniently placed cocks on the lower parts of the jackets will serve to blow out loose sediment or non-adhering scale. Careful settling of water before-

hand will generally eliminate the dangers from mud. The monthly injection of one pound of washing soda per 15 cubic feet of cooling water capacity in the tanks will generally convert the lime salts into soluble sludge, which may be blown out through cocks on the base of the tanks and those on the jackets.

323. **Removal of Scale from Jacket.** Incrustation may generally be removed from within the water-jacket by means of a 20 per cent. solution of hydrochloric (muriatic) acid. The jacket is filled with the acid and let soak for three or four hours, to dissolve the scale, which may be blown out as sludge. Care should be taken to avoid burns from the acid, also not to inhale its fumes. The jacket should be carefully washed out with water afterwards.

324. **Arrangement of Tanks.** It is not advisable to use reservoirs having a larger capacity than about 500 gallons, the usual diameter being three feet. Such tanks are fitted in series, the hot water entering at the top of the first, a pipe leading from its bottom to the top of the second, another pipe from the bottom of the second to the top of the third, and so on; the water supply to the jacket leading from the bottom of the last tank. If the natural circulation of the water be not sufficiently rapid, a small belt-driven centrifugal pump may be used to promote the flow through the jacket.

325. **Adjustment of Ignition.** Those engines supplied by good-class firms are always tried on the brake before leaving the shop. Still, as the quality of gas differs with every city, it is clear that some local adjustment must be made to suit the varying richness of the gas. No adjustment should be made without the use of the indicator, and periodical inspection by an expert is advisable.

326. **Starting a Gas Engine.** It is advisable to follow a regular routine, in order to prevent the omission of any detail, which may lead to mistakes and confusion. The following may be recommended:—

1. Oil the engine all around, trying the valve gear and governing mechanism, to see that all is clear and workable.

2. Inspect the cooling water supply, see that all cocks are open, and that the jacket drains are closed.

3. Open drain cocks on exhaust and gas-pipes to liberate any condensed water.

4. Light the ignition flame, if fitted with tube ignition, see that the sparking circuit is closed, if so fitted, placing the spark control in its backwardmost position, retarding the spark as much as possible. (See separate paragraphs on ignition.)

5. Open cock of valve box on engine or the test cock of the gas pipe.

6. Open the gas-supply cock from the meter, distending the bags, and forcing the anti-pulsator diaphragm out. As gas issues from the test-cock, apply a match to ascertain the quality of the gas, the flame being allowed to burn until it has gradually changed from a blue color to a bright yellow.

7. Set the engine in motion by means of the starting apparatus, the gas regulating cock being slowly opened to the proper mark on the dial. If no starting gear is fitted, pull the fly wheel round by hand until an explosion occurs. Never put the feet on the spokes when starting, or a bad accident may happen.

8. When the engine is properly running throw out the starting gear.

9. When the starting gear is out, bring the gas cock slowly to its full opening, and adjust the spark to suit the load.

327. Starting an Oil Engine. As the methods of vaporizing the oil vary considerably in the different makes, it is impracticable to formulate set rules. The following may be taken as hints rather than as instructions.

1. See that all strainers are clear and that the tanks are perfectly clean and full of oil.

2. The lamps and ignition device should be cleaned, and got ready, the oil pump being tried at the same time.

3. Light the lamps for heating the vaporizer or igniter, as in the Priestman or Hornsby-Akroyd.

4. Lubricate the engine thoroughly, testing all oil cups, and trying the governor gear by hand.

5. When the vaporizer or igniter is at the proper heat, usually a cherry red, the engine is ready to start.

6. Set the engine in motion, either by the starting device or by hand; in the latter instance, compression may be relieved by holding the exhaust valve open by hand.

328. Starting a Gasoline Engine. In addition to seeing that the reservoirs for gasoline and oil are full, that all connections are open, and that the sight feeds are working properly, attention must be paid to the following:—

1. That the sparking circuit is closed, involving examination of all switches. If the ignition apparatus consists of batteries and coils, trials should be made to ascertain whether the current passes at the proper time. This is done by completing the circuit with the contact on the secondary shaft, which should produce the characteristic hum or buzz caused by the action of the coil. A magneto apparatus is not so likely to get out of order and does not call for so frequent an inspection.

2. That the lever on the spark control quadrant stands at the extreme "back" position, retarding the spark to the utmost.

3. That the carburetter control lever is moved to the "open" position for insuring the *richest* mixture at starting, in order to develop initial power under the low suction prevailing as the engine first moves.

4. That the cock on the tube between fuel tank and carburetter is opened.

5. That the carburetter is in working order. This is ascertained by depressing the protruding end of the valve spindle or flusher; this act depresses the float, permits liquid to enter the chamber, and prevents the carburetter valve from sticking.

6. These preliminaries having been observed, it remains only to crank or bar the engine round. Under favorable conditions it is necessary to turn the engine over but once, through the suction and compression strokes, to the point of ignition. It will then take up the cycle and run without further assistance.

329. **Defective Compression.** Faulty compression is likely to prevent the ignition of the charge. The deficiency or otherwise may be ascertained by turning the engine around to the point of compression, when all valves are or should be closed. If but slight resistance be encountered, it is apparent that the charge is escaping through one of the valves or past the piston. The various channels of escape may be investigated as follows:

330. **Leaky Valves.** The valves, usually closed by their springs, may become hung up, from various causes. The stems may be clogged, which can be ascertained by manipulating them by hand or by a lever; this may be remedied by taking apart

and cleaning off the caked oil, the same applying to an obstruction which may prevent the valve closing. A worn valve may leak, this is only to be remedied by grinding in or renewal. In a new engine, the stem of the valve may bind in the seat, through fitting over-tight, which may be remedied by easing the stem with fine emery cloth and applying a little lubricant, cylinder oil for inlet and kerosene for exhaust valves.

331. **Leaky Exhaust Valve.** Other causes may militate against the effective operation of an exhaust valve. The spring may weaken through over-heating, or slackening of its compression nut, so that it has not sufficient tension to keep the exhaust valve closed against the suction of the charging stroke. This is remedied by renewal of the spring, tightening of the compression nut, by inserting a washer under the spring, or weighting the spindle (for a temporary repair). Lack of end play between the roller or wiper on the cam shaft and the valve stem, due to expansion of the latter, may prevent the valve from seating itself at all. This may be obviated by filing or regulating the contact.

332. **Leaky Piston.** The passage of the compressed charge, past the piston, is indicated by a whistling sound. This may be due to broken or worn rings, or to wear of the cylinder. The piston rings may be dealt with as mentioned in par. 310; if the cylinder is badly worn, reboring is likely to be necessary.

333. **Care While Running.** The engine having attained its normal speed an eye should be given to the governor, to see that it is acting properly, and that racing or "hunting" need not be feared. The electric spark must be set forward and the throttle partially closed. The cocks of the cooling water supply

should be set to the mark so as to maintain the proper cylinder temperatures. The working of the sight feeds should be inspected from time to time, to see that the bearings are getting their proper oil, and the crank pin and main bearings should be "felt around" every half hour. A very short experience of the engine room will enable the attendant to feel the crank pin brass while running, without risk of getting nipped, while absolute certainty of the condition of the journal will result from physical contact.

334. **Stopping Gas Engine.** 1. Close cock between meter and gas bag to avoid distension of the rubber bags.

2. Actuating the half compression or relief-cam, if fitted, to prevent reverse motion owing to compression.

3. Close gas cock between bags and engine.

4. Shut off burner of hot tube ignition.

5. Shut off cooling water supply; running water from jacket if weather be cold, or engine is going to be laid off.

6. Let the engine rest with crank at outer dead center of its compression stroke, all valves being then closed.

7. Close all sight-feed lubricators, remove worsteds or wicks from syphons, and shut down all oil box lids.

335. **Hot Tube Ignition.** Platinum and porcelain tubes are being superseded by a tube of nickel alloy, which is cheaper than the former and less fragile than the latter. The tube is heated by a Bunsen burner, and usually takes five or ten minutes after lighting to obtain its proper cherry red color. Care should be taken that the flame from the burner is blue, regulating the air admission, if necessary, by the sleeve over the air opening. A white or smoky flame, with a sooty odor, is an evidence of insufficient air supply; this color may also be caused by igni-

tion of the gas within the air space. If this happens, blow the burner out and relight it properly. A bluish or greenish flame has the highest temperature. If the flame flies back to the holes in the burner, it is short of gas.

336. **Electric Ignition.** As has been already stated, it is necessary to have the spark set late at starting, this is to avoid a premature explosion, causing a sharp revolution of the engine in the wrong direction. This condition of open throttle and late spark should never occur, except at starting, as it tends to waste of fuel, and the heat of the exhaust, owing to high terminal pressure, may damage the exhaust valve.

337. **Faulty Tube Ignition.** A porcelain tube may break at starting either through imperfect fitting or from the presence of water in the cylinder. A metal tube may carry away at the same time, generally because it is worn thin by use and cannot withstand the stronger explosion of the rich mixture at starting. A tube may also be choked by an internal obstruction or may be rendered faulty by leaks in its joints or in its body, whereby gas escapes and does not ignite. This latter is detected by a whistling sound.

338. **Water in Cylinder.** Water may be present in the cylinder from various causes:

1. A leak between the cylinder and the water jacket; betrayed by bubbles rising in the water tank at the time of explosion. This may necessitate the renewal of the cylinder or at least its working barrel, although plugging a hole or remaking a joint will generally suffice.

2. Bad arrangement of piping, causing entrained water to be brought in with the gas, or condensed from the exhaust and flow-

ing back. This is remedied by trapping the pipe or by elimination of bends and pockets on the exhaust.

3. Condensation of water created by the union of hydrogen and oxygen within the cylinder, or by electrolytic action, drops of water forming between the contacts of the spark plug.

Whatever its origin, water retards the explosion through chilling the gases and often renders it difficult to start the engine. To lessen the first cause of trouble, the cooling water cocks should always be shut when the engine is stopped. The cylinder drain cock should always be opened when starting. If no drain cock is fitted, the attendant difficulties can only be overcome by pulling the engine round and round and making ceaseless efforts to start it.

339. **Overheated Bearings.** These may be caused by undue tightness in setting up, by too much play, by lack of oil or by the use of a poor lubricant. The watchfulness of the attendant, feeling all the bearings while the engine is in motion, is the surest guard against anything serious developing. Liberal oiling at short intervals will often cool any bearing if applied as soon as a change in temperature is noted. If this be inadequate and it is undesirable to stop the engine, a spray of soapy water may be effective.

Where brass bearings are fitted, a little flowers of sulphur mixed with the oil is often effective; this should not be used on white metal or babbitt bearings, as the sulphur abrades the antifriction metal.

If the bearing is allowed to get properly overheated, the characteristic frying-pan smell of burnt oil will be perceived. If things have got so far, the engine must be slowed or stopped, as oil will only be burnt up, and clog all channels and oilways in the bearings. The temperature should be reduced by apply-

ing wet lumps of cotton waste and spraying with water. A small engine, when overheated, should have the affected part opened up, cleaned out, and the binding surfaces eased by scraping. If the heating occurs after adjustment, as is most likely, slacking back the nuts will generally remedy the trouble. In this case, a tin liner or shim should be fitted between the parts, so that the bolts are still in tension.

340. **Overheated Cylinder.** This may be due to stoppage or diminution of the cooling water supply, either through choking of the pipes or of the jacket. If the discovery is not made until the cylinder is very hot indeed, it is best to stop the engine and wait awhile, as the sudden turning on of cold water into a red hot cylinder may easily crack the cast iron. Restore the circulation gradually as the temperature approaches normal.

Again, it may be mentioned that a one-to-four solution of hydrochloric acid, used for washing out the jackets, will remove calcareous deposits. Of course, the jacket should be sluiced out with plenty of fresh water before coupling the water service again.

341. **The Spark Plug.** Formerly, nearly all ignition troubles were attributed to poor spark plugs. Now, we understand that such troubles arise from many other sources. Nevertheless, a spark plug is a delicate instrument, and one frequently deranged.

The commonest source of trouble is short-circuiting, due:

1. To breaking down of insulation, cracking in porcelain plugs, oil-soaking, deterioration of cement filling, or metallic impurities in mica plugs.

2. To fouling with soot between the electrode surfaces and spark points.

Troubles due to the first cause demand renewal of the plug. Fouling with soot may generally be removed with gasoline.

Preventives of fouling are:

1. An annular space between the core insulation and the outer shell, producing a vortex, as is alleged, and allowing piston suction to remove deposits.

2. An outside spark gap, which will generally suffice to insure a spark, but it does not prevent fouling between the spark points.

342. **Circuit Wiring.** The principal points for examination are:

1. The terminals and binding posts.

These should be firmly secured—all looseness being avoided—although crushing of the wires should be carefully guarded against.

2. The insulation, which should be examined for breaks, flaws or rubbed areas. By this means leaks and short circuits will be avoided.

343. **Defective Fuel Mixture.** It frequently happens that too *rich* a mixture will not ignite readily on cranking, and as a consequence, the engine will not start. It is necessary, then, to reduce the mixture, allowing more air to enter the carburetting chamber.

If the engine starts with a rich mixture, the result is liable to be seen in a heavy and ill-smelling smoke from the muffler. The color of this smoke will determine the nature of the trouble.

Dark-colored dense smoke indicates an excess of gasoline in the mixture, and may result from one of the following conditions:

1. A very rich mixture.
2. Imperfect combustion.
3. Defective ignition.
4. Either excessive or defective lubrication.
5. Overheating and consequent flashing of the lubricating oil.
6. A leaky piston.

The two most usual causes of dark smoky exhaust, however, are:

1. Defective carburetter action, due probably to grit under the inlet needle valve, or else to some derangement of the parts.

2. An over-rich mixture, which ignites imperfectly.

White dense smoke indicates an excess of oil or a resulting deposit of carbon soot in the cylinder, or a poor oil that is liable to flash at low temperatures.

Thin blue, or nearly invisible smoke indicates a normal mixture and good ignition.

An unpleasant odor in the exhaust is frequently mentioned as the one necessary evil of motor carriage operation. This is incorrect, as the odor most often indicates poor lubricating oil or too rich a mixture, involving waste of fuel. A good mixture, perfectly ignited, in a cylinder lubricated with high test oil, should have no very bad odor.

344. **Reducing Smoke in the Exhaust.** Smoke from the exhaust being a sure indication of oil-flooding or too much gasoline in the fuel mixture, demands attention to the *oil feed* and *carburetter,* as follows:

1. Reduce rate of oil feed, if the smoke indicates oil. If this is the sole trouble, the smoke will decrease after a few revolutions of the fly-wheel.

2. Restore the oil feed nearly to normal and adjust the carburetter.

3. Examine the air inlet of the carburetter, and cleanse the gauze screen of any dust. This will restore the air supply.

345. **Dangers of a Smoky Exhaust.** A smoky exhaust, indicating the presence of excess oil or carbon deposits in the cylinder, should serve as a warning in one respect. The soot formed is liable to take fire and smoulder, causing pre-ignition, particularly under heavy loads. If, after other relief measures have been tried, the nuisance persists, the cylinder interior should be cleaned at the earliest opportunity. In cold weather considerable watery vapor appears in the exhaust.

346. **Causes of Defective Mixtures.** An over-rich mixture—one containing an excess of gasoline vapor—may be caused by any one of several conditions, prominent among which are:

1. An air inlet clogged with dust or ice on the gauze.

2. A piece of grit or other object preventing closure of the needle valve.

3. A leaky float which has become partially filled with liquid gasoline, and is, therefore, imperfectly buoyant. This should be repaired by soldering.

A poor mixture may be caused by:

1. An excess of air drawn through some leak in the air pipe.

2. Water in the gasoline.

3. A feed pipe or feed nozzle clogged with lint, grit or other obstructions.

The quality of the mixture may generally be determined from the effects on the operation of the engine. If it is not obvious in this manner, it may be determined by actual test.

This may be done by removing the peep cap or plug from the cylinder, and applying a match. A too-rich mixture burns yellow, one too poor will not ignite or else will be faintly blue, one correctly proportioned will cause an explosion. If it seems too poor, flooding the carburetter will prove whether the impression is correct or not.

347. **Causes of Back-firing.** Back-firing, or pre-ignition, may occur under several conditions. Prominent among these are:

1. An early ignition, at or before the backward dead-center of the crank, before the cycle is established, as in the act of cranking the engine for a start. The result is then a *back-kick,* or reverse revolution. This can only emphasize the necessity of retarding the spark at starting, so that it will not occur until the dead-center is fairly passed over, and the piston has begun the outstroke.

2. Overheating of the cylinder walls, due to insufficient heat radiation (in an air-cooled engine) or too little jacket-water (in a water-cooled engine). This should emphasize the necessity of keeping the water supply sufficient for all needs, and of assuring the perfect operation of the circulation system, pump, radiator, etc., before starting the engine.

3. Soot deposits within the combustion space, due to carbonization of excess oil, etc. Such deposits will readily ignite and smoulder, and will thus furnish an almost certain source of ignition, during the compression stroke.

4. By attempting to increase the power-output of the engine, when operating on a heavy load, by advancing the spark too far. In this case, the conditions causing back-kick at starting are closely approximated as the engine is running too slow for an early spark.

348. **Water in the Carburetter** will often prevent starting of the engine, and will always impair its efficiency. Water is very frequently present in gasoline, and, particularly when the tank is low, is liable to get into the pipes and carburetter. Every carburetter has a drain cock at the bottom to let off the water that settles from the gasoline.

The natural result of water in the carburetter is impaired or interrupted vaporization of gasoline.

In cold weather, also, the water is liable to freeze, preventing the action of the carburetter parts and clogging the valves. Ice in the carburetter can be melted only by the application of hot water, or some other non-flaming heat, to the outside of the float chamber.

It is not at all necessary to drain the carburetter before every starting, but after a prolonged period of inactivity it is desirable to give the water an opportunity to escape.

A strong presumption of water in the carburetter is established when the engine starts, runs fitfully, or irregularly, and finally stops.

349. **Stale or Low-Degree Gasoline.** Another condition that will produce some of the same symptoms is low grade or stale gasoline. These two varieties of spirit are practically identical, in effect at least, both being characterized by a lower specific gravity than is required for readily forming a fuel mixture. Gasoline, or petrol spirit, as it is called in England, should have a specific gravity of about .682, or 76°B. Some English authorities recommend spirit having a specific gravity of from .72 to .74, or between 65° and 59°B, virtually what is known in the United States as high-grade benzine. Hydrocarbon spirits of lower degree on the Baumé scale become increasingly difficult to vaporize.

Gasoline, being a volatile essence distilled from petroleum oil at temperatures ranging between 122° and 257°F., and boiling at between 149° and 194°, on the average, is a compound of several spirits of varying density, gravity and volatility. Chemically, it is represented by formulæ ranging from C_5H_{12} to C_7H_{16}, with the average C_6H_{14}. It follows, therefore, that, unless stored in an air-tight vessel, the lighter constituents are liable to escape, leaving a residue that will show a registry on the Baumé scale below that found easiest to vaporize.

This is the process that occurs in the carburetter, if gasoline is allowed to stand in it for any length of time. It is always best, therefore, after standing for a protracted period, to drain the carburetter.

Of course, if the tank is found to contain only low-degree liquid, the only alternative is to empty it and refill with a supply of the proper quality.

350. **Causes of Failure to Start.** If all preliminaries, hitherto specified, have been carefully observed, and the engine shows good compression at cranking, the probable causes of trouble should be sought:

1. In the sparking plug.

The spark-points may be too far apart; there may be fouling between them; the plug may be short-circuited, or the insulating layer of porcelain or mica may be broken down.

2. In the carburetter.

The spray nozzle may be clogged; there may be water in the float chamber; low grade gasoline may be used; too much or too little air may be admitted. The supposed carburetter trouble may be located in the fuel tank or supply pipe; in the throttle or may be due merely to faulty valves.

3. In the battery.

The battery may be run down or polarized.

4. In the circuit wiring or connections.

There may be a short-circuit, due to a broken wire or defective insulation, or there may be a looseness at some binding-post.

5. In the vibrator of the coil.

There may be a defective adjustment of the vibrator, preventing it from responding to the strength of current in use, or the vibrator may be broken loose.

6. In the interior of the coil, as previously explained.

351. **Fouling of the Spark Plug.** Persistent failure to start, when buzzing of the induction coil vibrator indicates that the electric circuit is in working order, may be attributed to fouling of the spark plug. Fouling may consist of liquid oil or soot. Both give most trouble at starting.

Fouling may be removed:

1. By using a well-made spark-gap arrangement.

2. By a temporary spark-gap, made by disconnecting the lead wire of the plug and holding its end at a sufficient distance to allow a visible spark to leap from it to the plug core.

If this proves ineffective, the plug should be unscrewed and examined. Any visible fouling may then be removed by rubbing the insulation with fine emery paper until the bright surface of the porcelain is visible, taking care not to impair the surface.

352. **Testing the Spark Plug.** If no fouling appears, the plug may be laid upon the cylinder or frame so that its case only is in contact, and thus grounded, and on cranking the engine, the spark may be seen leaping between the points.

If a spark does not appear, it is probable that, with the ignition circuit in working order, there is some breakage or short

circuit in the body of the plug. This, of course, necessitates its removal and the substitution of a new one. If a spark appears, the search for trouble must be continued to other apparatus.

353. **The Spark Points of a Plug.** Very frequently a perfectly sound plug will fail to spark, simply because the spark points, for some reason or other, have been too greatly separated, or else because the battery is nearly exhausted. In either case the trouble may be overcome by bringing the spark points nearer. For average strength of battery, the distance between the points should be about 1/32 inch, and practically never more than 1/16 inch.

354. **Failures with Four Cylinders.** Unless the ignition circuit is elsewhere disarranged—in battery, coil or wiring—failure to start in a four-cylinder engine is probably due to causes other than foul or defective spark plugs. It may happen, however, that one, or even two, of the cylinders will fail to ignite. This condition will show symptoms similar to those caused by mis-firing, irregular movement and vibration.

355. **Testing for the Missing Cylinder.** In practically all four-cylinder engines made at the present day the cranks of the second and third cylinders are in line, and are set at 180° to the cranks of the first and fourth, which are also in one line. Consequently, the pistons of the second and third cylinders make their instrokes at the same time as the first and fourth make their outstrokes. As a rule, the order of ignition is: first, third, fourth, second, which is also the order in which the primary circuit is closed at the commutator through the primary winding of each coil in succession.

In order, therefore, to determine which cylinder, if any, is missing fire, it is necessary only to open the throttle and advance the spark lever to the running position, giving the engine

good power, and to cut out three of the four cylinders by depressing their coil vibrators. If the engine continues to run with coils 2, 3 and 4 cut out, cylinder 1 is evidently working properly. Depressing vibrators of 1, 3 and 4 shows whether 2 is working; of 1, 2 and 4, whether 3 is working, and of 1, 2 and 3, whether 4 is working. On discovering the faulty cylinder, its plug may be tested precisely as is the plug of a single-cylinder engine.

An exactly similar process may be followed in the search for a missing cylinder of a three or six-cylinder engine.

A missing cylinder may also be found by the low temperature of its exhaust pipe, provided the missing be long continued.

356. **Misfiring During Operation.** Occasionally, the missing of one or more of the cylinders will be noticed during the operation of the engine. This trouble may be recognized by irregularity of motion, gradual slowing down, and, generally, by *after-firing,* or explosions in the muffler. If, by the coil-cut-out test, just described, it be found that one particular cylinder is at fault, it is fairly probable that a faulty spark plug, a loose wire in the secondary circuit, or a sticking valve is the cause.

If the trouble cannot be thus located in one of the cylinders the inference holds; either that there is some general derangement of the ignition circuit, or that the fuel mixture is not right.

357. **Misfiring: Short Circuits.** Very frequently misfiring is caused by a short circuit, which is to say a ground, or an arcing gap between the two sides of the secondary circuit, at some point short of the plug terminals. This will, of course, prevent sparking at the plug, although, owing to the vibration

of operation in the other cylinders, the short circuit may occasionally be interrupted and the spark will occur.

Such a short circuit differs from an *extra spark gap,* in that the latter is *in series* with the plug gap, while the former gives a leak *in parallel* to it.

A broken-down coil, or one in which the insulation is weakened, allowing internal leaks and sparking, will cause misfiring for a time, and will very soon be of no use whatever.

358. **Misfiring: Loose Connections.** Loose connections of the wires at a binding screw, in either primary or secondary circuit, may cause misfiring, or irregular firing, in very simi.ar fashion. The looseness may be small, or it may be excessive, and the condition in this respect determines the degree of interference in engine operation. Thus, a loose connection may allow the engine to run from rest to a moderately good speed before trouble begins, or the vibration of operation may interrupt the contact entirely. This only emphasizes the necessity of keeping connections tight. Spring connections are much used now.

359. **Misfiring: Weak Battery.** As we have already learned, a weak battery may prevent sparking between the plug points, and can be remedied in no better fashion—provided no extra battery be at hand—than by reducing the gap between the points. As a consequence, a weak battery is a frequent cause of misfiring.

Misfiring due to a weak battery may be diagnosed by the occasional apparent violence of the explosions, on account of frequent misses. A weak battery will cause misfiring most conspicuously when the engine has been run up nearly to full speed, and then suddenly drops, owing to irregular ignitions.

The reason is, obviously, that the weak battery cannot supply good fat sparks at a rate commensurate with the requirements of rapid operation. With a reduced spark gap and a slow speed, it may be able to continue operation for a limited period.

These principles apply, of course, to chemical batteries. When the current is obtained from a magneto or dynamo, the trouble—if traced to the source—is probably due to loose or worn brushes, a glazed commutator, or a short circuit somewhere in the armature, or around the brush holders.

360. **Misfiring at High Speeds.** Among other causes of misfiring at high speeds may be mentioned a faulty adjustment of the coil vibrator, giving extremely short *makes* of the primary circuit and slow rates of vibration, which cannot keep pace with the requirements of high engine speeds.

Loose circuit connections, shaken out of position as the engine speeds up, and weakened batteries are far more common causes of this mishap at high speeds, as already indicated.

361. **Misfiring: Defective Mixture.** A defective mixture will frequently occasion misfiring, on account of difficulty of igniting. Such a defective mixture may be one that is either too rich or too weak, and may be produced by a flooded carburetter, one in which sticking, or some similar disorder, prevents the feeding of sufficient gasoline spray for a good mixture.

In either case the ignition of the charge is slow, if it occurs at all, and the result is that unburned gas is discharged into the muffler, producing after-firing and reducing the power efficiency.

362. **After-Firing in the Muffler.** After-firing, or "barking," sometimes incorrectly called back-firing, and consisting of a series of violent explosions in the muffler, is commonly caused

by misfires in one or more cylinders, permitting the accumulation of unburned gas in the muffler, which is ignited by heat of the walls or by the exhaust of firing cylinders. Sometimes it may be due to a mixture that is too rich or too weak, and hence burns slowly, continuing its combustion after passing into the exhaust. It also occurs, not infrequently, when the spark is retarded to slow the engine before stopping. No particular harm results from this rather startling effect, since the explosion can seldom occur until the unburned gas comes into contact with the outer air.

363. **Running Down.** When the engine starts well, runs for a while, then slows down and stops, there are very many conditions to which it may commonly be attributed. Among these are:

1. Water or sediment in the carburetter.
2. Loose connections, break-downs, or any other disarrangement of the ignition, such as would otherwise interfere with starting.
3. A weak or imperfectly recuperated battery—frequently the latter—that suddenly fails to supply current.
4. A leak in the water jacket that admits water to the combustion space.
5. Seizing of the piston in the cylinder on account of failure of the cooling system. This may result, in a water-cooled cylinder, from:

    a. Exhaustion of the water.
    b. Stoppage in the pipes or pumps.
    c. Breakdown of the pump.
    d. Failure of the oil supply.

In an air-cooled cylinder seizing may result from:

  a. Insufficient radiation surface.
  b. Obstructed air circulation.

6. Heated bearings that seize and interfere with operation.

7. Poorly matched or badly adjusted new parts, particularly pistons, that cause heating, and perhaps seizing, from friction.

8. Lost compression from broken or stuck valves, leaky piston, etc., as explained in the succeeding paragraph.

364. **Low Compression Troubles.** Practically all the mishaps hitherto mentioned may occur with a good compression, which may be recognized on turning the starting crank. When little or no compression manifests itself as a resistance to the turning of the crank, it is certain that the operation of the engine will be defective, provided it can be started at all. If the engine loses compression after it has started, it will misfire and slow down.

Low compression means absence of a sufficient quantity of gas mixture to give a good power effect. This absence results from a leak in the combustion chamber, due to:

1. A sticking inlet valve—if the inlet be automatic—from an incrustation of oil gum. Sticking may be due to other causes also.
2. A pitted or corroded exhaust valve.
3. A weak spring on the exhaust valve.
4. A loose or open compression tap.
5. A leaky piston, due to:
   a. Worn or broken rings.
   b. Piston rings worked around, so as to bring the openings on their circumferences into line.
6. A blown-out gasket in the cylinder head.
7. A worn or loose thread at the insertion of the spark plug.
8. A broken valve or valve stem.
9. Worn or scratched sweep wall, due to lack of oil or the presence of grit.

10. A valve-stem that is so long as to touch the end of the pushrod when the engine is cold. The remedy for this is to file the end of the valve stem until a card may be inserted between its end and the end of the pushrod.

365. Unusual Noises. There are many troubles of varying gravity that are manifested by no other symptoms than noises, more or less regular, during the operation of the engine. Such noises always indicate trouble, and should not be ignored by the careful motorist.

There are certain rhythmic sounds that are always produced during the operation of a gasoline engine, and the motorist soon learns to recognize them. They are the regular rattle of the automatic inlet valves, the roar of the gears and cams, and the puffing of the exhaust.

Present-day engines are far less noisy than those built several years ago, principally on account of:

1. Better balance of the moving parts.
2. More efficient and better adjusted mufflers.
3. The extensive use of the mechanically operated inlet valves.
4. Better gears and cams.
5. The use of housed gears.

Unusual noises, indicating trouble, may be described as:

1. Knocking.
2. Squeaking.
3. Hissing or puffing.
4. Numerous irregular puffs and pops.

366. Knocking in the Cylinder. The form of unusual noise commonly described as "knocking" consists of a regular and continuous tapping in the cylinder, which is so unlike any sound usual and normal to operation that, once heard, it cannot be mistaken.

367. **Knocking Caused by Over-Rich Mixture.** Knocking, with all the features of that caused by an over-early spark, may sometimes result from an excessively rich mixture, which may ignite too slowly or too rapidly. Here, as in the general operation of the engine, the rule holds that spark-advance and charge-enriching amount to the same thing, so far as the results are concerned.

If retarding the spark from the extreme lead fails to overcome the knock, the mixture may be throttled with good probability of success.

368. **Other Causes of Knocking in the Cylinder.** The knock caused by a premature spark is a heavy pound. The knock caused by some other defects is often less severe. Among other causes of knocking may be mentioned:

1. Defective lubrication or burned oil, leading to a tendency to overheat and seize. This trouble develops rapidly, and demands instant attention, as soon as recognized.

2. Over-late or disordered ignition, producing an explosion during the suction or exhaust strokes. Such an explosion has very little force and is best described as a "pop."

3. Loose or broken piston rings.

4. Broken wrist, or gudgeon, pin in the piston. This is the part of the engine that receives a large share of stress in a high-compression engine, such as is used on most pleasure carriages at the present time.

5. Irregular wear in the cylinder.

As mentioned by numerous authorities, the placing of the spark plug in the exact centre of the combustion space occasions a peculiarly sharp knock, which may be stopped by advancing or retarding the spark from the one point of trouble.

This explanation of the trouble is questioned by others, and is probably over-rated.

369. Knocking Outside the Cylinder. Knocking, or long-continued tapping or pounding, is not always within the cylinder itself. The effect may result from several mechanical causes, such as:

1. Loose bearings at the wrist or crank pin, giving one knock at the moment of explosion, and another at the change of stroke.

2. Lack of alignment between the connecting rod and the crank pin or wrist pin, which forms a very serious source of trouble. An engine will run with its connecting rod and bearings out of line, but the trouble should, of course, be remedied at the first opportunity.

3. Loose, worn or broken parts at the bearings, in the fly-wheel or in some nut or bolt. Considerable trouble may be caused by a loose fly-wheel, which is a derangement particularly difficult to determine.

370. Squeaking in the Engine. Squeaking, evidently caused by the rubbing of one part upon another, is a sure sign of insufficient lubrication, probably in some bearing outside of the cylinder, although perhaps at the wrist pin of the piston. Faulty lubrication between the piston and cylinder wall would produce much more serious results than noise, as already stated.

371. Wheezing. A wheezing sound, evidently due to the escape of gas or air under pressure, and sometimes amounting to a squeak, is often caused by loose or worn piston rings or scoring of the cylinder bore. The causes of this trouble are, as already suggested:

1. Deficient lubrication, producing a tendency to seize.

2. Misalignment of wrist pin and crank pin, or a bent rod, causing the bore to wear oval. This trouble generally results from repeated back-firing, from an over-early spark and the other causes specified.

The signs of a worn cylinder bore or loose or broken piston rings, should be immediately observed. They indicate the most serious occasions of loss and failure possible in a gas engine.

372. **Hissing or Puffing Sounds.** While leakage at the piston gives forth a sound that may be described as "wheezing," on account of the imperfect venting of the compressed gas, the escape of such gas into the atmosphere is accompanied by hisses or puffs. Such sounds indicate the probability of leaks:

1. At the gasket in the cylinder head, if a joint exists above the piston.

2. At the insertion of the spark plug, due to a worn screw thread or washer.

3. At the valve seats, due to pitting or to an improper fit of the valve.

Leaks of this character are liable to occasion continuous cracking sounds during the firing stroke.

At least a moderate amount of care should be paid to the arrangement of the exhaust from a gas engine, for it will be amply repaid by the avoidance of many sources of trouble.

It has been found that a straight exhaust pipe, in length about 100 times the stroke of the engine, will produce a *scavenging effect.* The products of combustion will attain so great a velocity that they will create a suction in the combustion space of the cylinder, thus freeing it from the remainder of the burnt charge. If some sort of stratification is applied to the mixture, the admission valve may be set to open before the

conclusion of the exhaust stroke, thus blowing air into the clearance space, and assisting the scavenging action.

With mixed ignition governing, however, the unexploded charge is apt to communicate with both the hot exhaust and the fresh incoming charge, thus rendering early opening of the admission valve a cause for premature ignition.

The exhaust pipes should be as straight and free from bends as possible, the necessary curvature being made very easy. The most effective silencer is afforded by the attachment of a straight trumpet-shaped conical nozzle to the end of the exhaust piping, the cross-sectional area of this being proportional to the desired velocity of the gases. This velocity may be calculated as ranging from 2,500 to 3,000 feet per minute at the commencement of the exhaust.

In expanding from 40 lbs. terminal pressure to that of the atmosphere, the volume of the gases increases three-fold. The mouth of the nozzle should therefore be nearly twice the diameter of the exhaust pipe, and the length of the cone should be twelve times its initial diameter.

A steel muffler box is apt to act as a resonator or intensifier of sound, so the exhaust is best led into the bottom of a masonry well. The exhaust chamber should have a capacity of fifteen to twenty times the cylinder displacement, its upper portion being filled with broken rocks laid on a wide grating. These rocks should be well hosed down at regular intervals to wash off the dirt from the exhaust, water and all being carried away by a drain in the bottom of the chamber.

A separate exhaust pipe should be led to the well from each engine in a plant. If it is necessary to connect two or more units to one exhaust main, a shut-off valve should be fitted to each branch, and connections must be made with Y-pieces.

CHAPTER XXVI.

THE AUTOMOBILE.

373. **Types of Automobiles.** The term *automobile*, or its equivalent, *motor-car*, is somewhat loosely applied, but may be considered as signifying a self-propelled vehicle designed to run upon ordinary roads, and transporting passengers and commodities beyond those necessary for its own guidance or consumption. Two important exceptions are made from this classification: small vehicles, with two, three or four wheels, built along the lines of a bicycle, are separately classed as motor cycles, tri-cars or quads; various machines, such as road-rollers, traction engines, and the like, are also considered as being in a different category, although heavy slow-moving vehicles intended solely for the transport of merchandise are classified as heavy motor-cars or motor-trucks.

374. **Power for Automobiles.** The three chief sources of power, applicable to the propulsion of automobiles, are electricity, steam, and the light oils of petroleum.

Electricity is handicapped by the excessive weight of the accumulators necessary to develop a small power, and the need of recharging them at short intervals, this is due to the employment of lead and lead oxides as the chief constituents of the storage batteries. Still, for private use, more especially within cities, where the distances traversed are short and the proportion of stoppages large as compared with time in motion, the electric vehicle is largely the favorite on account of its silence, cleanliness and freedom from odor.

Steam has found great favor on account of the easy management of the working fluid, the absence of spur-gearing, freedom from ignition troubles, and the reduced cost of repairs due to lessened vibration. These advantages are counterbalanced by the extra care necessitated by a boiler and the cost of fuel, which most usually is some petroleum product whose efficiency is far less when burned under a boiler than when consumed directly within an internal combustion engine. Steam has its most effective application in heavy mercantile vehicles, where small tare weight is not a matter of great importance, and coke or anthracite may be used for fuel, which is fed into a generator that is a sort of combined water-tube boiler and gas producer.

The majority of self-propelled vehicles, for all purposes, save those previously indicated, are driven by explosion engines using petroleum spirit or light, volatile, hydrocarbons as fuel. The general arrangement of parts and nature of details are, broadly speaking, the same as previously described in Chapter XX. The engines of motor vehicles work almost invariably upon the Otto or four-cycle principle, weight being kept down by adopting a high speed of revolution, together with the use of specially strong steels and bronzes to insure light construction. The electric spark is universally employed as the means of ignition. A section of a typical motor is given in *Fig.* 147.

375. **Fuel for Motor Cars.** Crude petroleum varies in its constitution and consequently in its specific gravity, according to the locality of its origin, varying from 0.790 to 1.010. It is a highly complex mixture of many more or less volatile hydrocarbons, principally paraffins with some olefines. The oil is distilled in fractions, which are separated according to their boiling points. The most volatile part boils at from 113° Fahr.

to 138°, this is known as *petroleum ether;* the next product, boiling from 140° to 158° Fahr., is termed *gasoline*; *benzine* comes over from 160° to 200° Fahr., and is followed by various

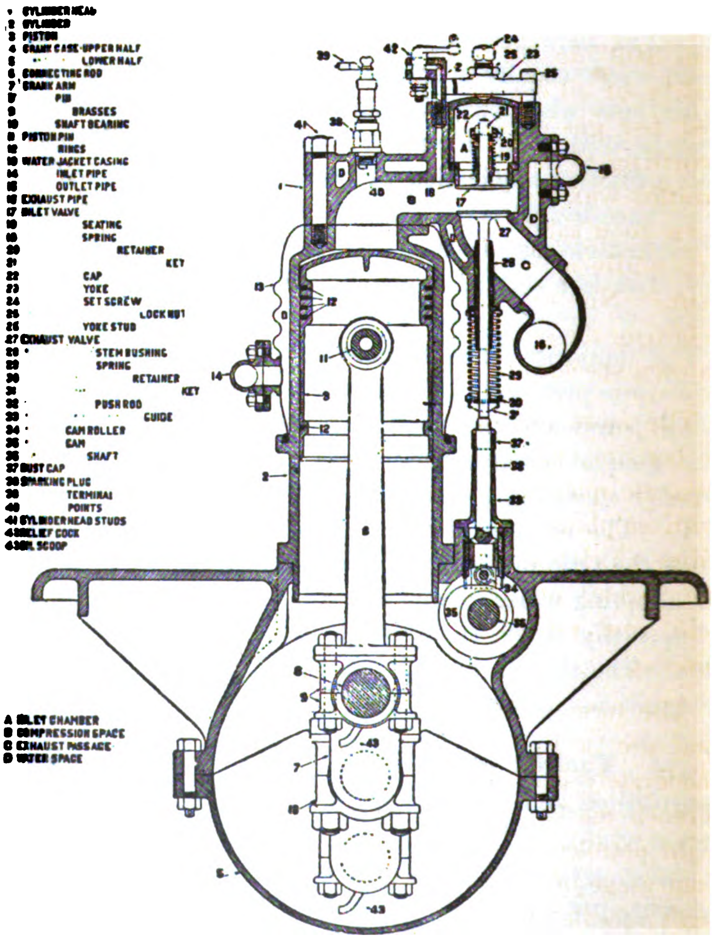

Fig. 147.—Section of Typical Automobile Motor.
(Paragraph 374)

naphthas, evaporating at points ranging from 200° to 300° Fahr. The foregoing are all combined to make American commercial gasoline, various fractional distillates being taken at intermediate points for such substances as benzoline, naphtha, etc. *Kerosene* or *illuminating oil* is boiled over at a range from 300° to 500°, the extent of the cut depending upon the quality of oil demanded; this is followed by *gas-oil* or *solar oil,* used for gas enrichment. The residuum is variously treated according to the products desired; lubricating oils, vaseline and paraffin wax are obtained from certain oils, which are distilled down to a solid coke, others may yield lubricants and then a tar; while some may be burnt as fuel without further treatment. No two petroleums are alike, East Indian kerosene weighing the same as Pennsylvanian residue, and each demands its own special processes of distillation and refining.

The more volatile products, known commercially as gasoline or benzine, are redistilled, usually by steam heat, to obtain separate qualities; these as well as the kerosenes are agitated with sulphuric acid to remove carbon particles or other impurities which tend to impair the qualities or color of the oil; next, the various products are treated with soda to neutralize free acid, and repeatedly washed. This constitutes the refining process.

The term *petrol,* as applied to automobile fuel, is in general use in England and upon the Continent. Petrol was a moderately heavy benzine, the first available fuel put on the French market, but the term has been extended to cover all light petroleum products, much in the same way as the American usage of the term *gasoline* has widened to include all the light volatile hydrocarbons known to refiners the world over as *benzine.*

376. **Classification of Vehicles.** Automobiles are generally classified according to their size and the character of the accommodation provided by the carriage body. Roughly speaking, for passenger cars, the classes are:—

Runabouts; small cars usually carrying only two persons.

Light Cars; of moderate power, ordinarily built to accommodate four persons.

Touring Cars; long distance vehicles, carrying from four to six, or more, with provisions for an extended trip.

Broughams,
Landaulets,
Omnibuses,
} Arranged according to the practice in horse-drawn vehicles, as the name would suggest.

Many other types appear from time to time, chiefly differing in the arrangement of the seats or in protection against the weather. A well-known class is the *Limousine,* in which the rear seats are enclosed within a carriage body, the front or driver's seat being protected by a canopy only, or perhaps a glass screen.

377. **Essential Elements of an Automobile.** While in this age of the world it is impossible to assert that any device is perfected or that any has reached a finality, it is admissible to assume, for practical purposes, that recognized standards of construction are permanent. The essential features will be taken up in turn, therefore, describing their construction and explaining their uses. These may be summed, as follows:

1. The power developed by a motor carried on the running gear is applied to the rear wheels, or to a rotating shaft upon which they are secured.

2. The two driven wheels must be so arranged as to rotate separately, or at different speeds, as in turning corners. For

this reason, the compensation or differential gear is an essential element.

3. The two forward or steering wheels, studded to pivots at either end of a rigid axle-tree, must be arranged to assume different angles in the act of turning, in order that the steering may be positive and certain.

4. The body of the vehicle must be set relatively low, or the wheel-base, the length between forward and rear wheel-centers, must be relatively long, in order to obtain the best effects in traction, steering and safety.

5. The springs must be of such strength and flexibility as to neutralize vibration, absorb jars and compensate any unevenness in the roadway.

6. The distance between the motor and the driven wheels must be bridged by adjustable radius or reach-rods in order that the drive may not be interrupted by the vibrations of travel.

7. The wheels must be shod with pneumatic, or other forms of tires of sufficient resiliency to protect the machinery, running gear and passengers, from jars and shocks otherwise inevitable at high speeds on ordinary highways.

8. Positive and powerful brakes must be provided, in order to secure effective checking of motion, whenever required.

9. All parts must move with as little friction as possible, in order to save power for traction. For this reason, ball or roller bearings are generally used on all rotating shafts of motor carriages.

10. Convenient and efficient means for ready and liberal lubrication of moving parts is a constant necessity.

11. Balance of parts and stable construction are required to reduce wear and friction.

12. Simplicity of structure and ease of handling and repair are the prime requisites of the best automobile.

13. All working parts must be of sufficient size, weight and strength to endure the jars of travel, and be serviceable under all conditions. There may be some advantages in the light construction, formerly supposed to be essential, but present-day practice recognizes the evident fact that strength and durability are more important considerations.

378. **Driving Parts of an Automobile.** A sectional elevation of a 50-horse-power, four-cylinder car is given in *Fig.* 148, a plan of the same car being shown in *Fig.* 149.

The lower part of the car is known as the *chassis;* this term includes the framing, the supporting wheels, the propelling machinery and transmission gear, the steering mechanism, etc. Except with heavy motor vehicles, it is customary to build the various chassis, for the same power of engines, of uniform dimensions, the various types of body being fitted to similar chassis according to the desires of the purchaser.

The essential propelling elements of an automobile, using petroleum spirit, are as follows:—

1. The fuel tank, containing a supply of gasoline, petrol or other variety of petroleum product.

2. The *Vaporizer* or *Carburetter,* in which the liquid fuel is vaporized or atomized and mixed with air to form an explosive mixture.

3. The *Engine* or *Motor,* in which the explosive mixture or charge, drawn from the carburetter, is compressed, ignited, expanded and the burnt gases expelled; by which process as much as possible of the available heat of the fuel is converted into power for driving the vehicle.

4. The *Radiator* or *Cooler*, subsidiary to the engine, an arrangement of cells or tubes with projecting fins or webs,

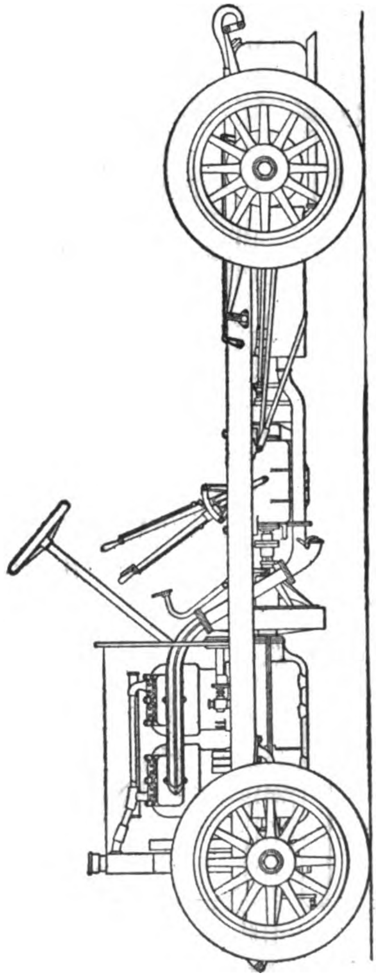

FIG.—148.—FOUR-CYLINDER AUTOMOBILE CHASSIS; 50-HORSE-POWER. (Paragraph 878.)

wherein the cooling water for the cylinder jackets is reduced in temperature, by exposing as large a surface to the air as

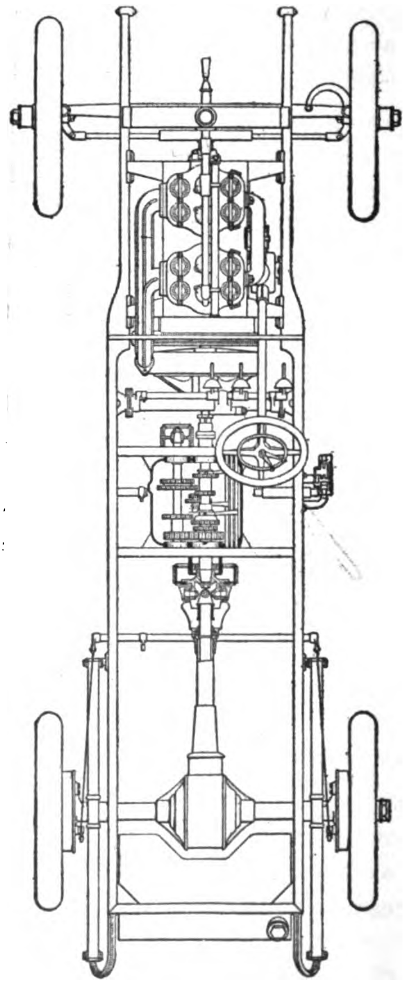

FIG. 149.—PLAN OF 50 HORSE-POWER CHASSIS.
(Paragraph 878)

possible; this dissipates the waste heat of combustion by the effects of radiation. Some engines are air-cooled, that is, the cylinders are provided with deep fins or projecting spines to expose a large area to the air driven among them by a fan and the progress of the car.

5. The *Muffler* or *Exhaust Silencer,* whereby the products of combustion are discharged into the atmosphere. This is a chambered and partitioned vessel, wherein, by gradual expansion of the gases, the noise of the explosion is lessened.

6. The *Clutch,* by means of which the employment of the power is controlled, the engine, which revolves whether the car is running or not, being connected at will with the transmission gearing, or disengaged therefrom.

7. The *Change Speed Gear,* by means of which the relations between the speeds of the driving and driven mechanism may be varied to suit the gradient on which the car travels, the same gearing also provides means for reversing the motion of the car.

8. The *Transmission Gearing,* which transmits the power of the engine to the driving wheels, either through bevel or spur gearing, or by means of chains traveling on sprocket wheels.

9. The *Tires,* generally pneumatic, or inflated with air, in order to be able to move at high speeds without excessive vibration and wear and tear in the working parts.

The propulsion elements of a steam car are in some measure identical. Owing to the possibility of stopping the motor while the car is stationary, the clutch is dispensed with in these cars; and, as the steam answers to throttling, a change speed gear is unnecessary. The condenser takes the place of the radiator, leaving the boiler additional, its weight being to some extent counterbalanced by the absence of change and clutch gear.

379. **Description of Details.** The usual form of carburetter is of the "spray" type, the fuel being atomized from a jet or nozzle, mixed in that state with the air supply; the flow of the liquid is regulated by means of a cork or hollow metal float within a chamber of the carburetter (See par. 232, 233 and *Figs.* 110, 111.)

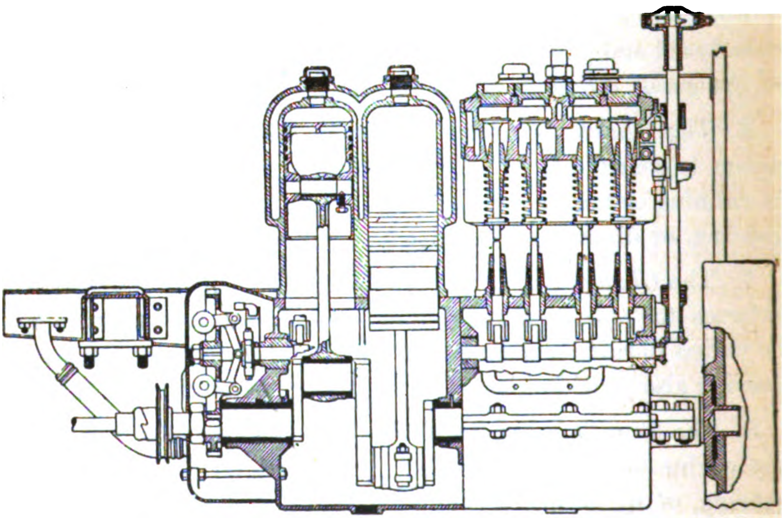

FIG. 150.—PART SECTIONAL ELEVATION OF THE PACKARD FOUR-CYLINDER ENGINE. Showing method of driving the inlet and exhaust valves from a single cam shaft. (Paragraph 379.)

As already stated the gasoline motor, commonly employed, works upon the Beau de Rochas or Otto cycle, receiving an impulse on each piston, during each fourth stroke. The number of cylinders in general use ranges from one, in small cars, to six or more in the better class of touring car or high-powered machines specially built for racing purposes. As has been shown in paragraph 145, the employment of a multicylinder engine produces more uniform turning effort, lessens vibration

by counterbalancing disturbing forces, and permits smaller parts through splitting up the power between a number of cylinders.

A section of a four-cylinder engine is given in *Fig.* 150, which will be seen to be a compact arrangement similar to other engines illustrated. The cylinders are usually cast in pairs, as shown, together with their pedestal or standard, which is bolted direct on the sole-plate of the engine. The crank pins are placed in pairs opposing each other; thus, in a four-cylinder car two pistons would be at the top center and two at the bottom; in a six-cylinder engine the cranks would be arranged in pairs 120° apart. The former arrangement gives two impulses at each revolution, the latter providing three. It will be observed that the valve gear illustrated is the same as that previously shown on a larger scale in *Fig.* 45.

Radiators or coolers are of quite varied designs, the object in each case being to expose as large a surface as possible to the air. The water is carried in a tank slung near the rear or driving axle, is forced by means of a small centrifugal pump through the water jackets, passes to the radiator and returns to the supply tank once more. Fans or propellers, belt driven from the crank shaft, are frequently employed to assist the radiator, drawing air through it from forward, and discharging over the outside cylinder casing, thus keeping down the temperature inside the bonnet.

Air-cooled cylinders have been successfully tried, the radiating surface being provided by gills or ribs on the cylinders, or by solid or tubular spines screwed radially into the outer cylinder wall. A fan is indispensable in this connection.

Clutches are made of different designs, some constricting around the other part to effect engagement, while others expand

for the same purpose. Some type of rigid cone is usually employed, effecting engagement or disconnection at will between the intermediate shaft and the fly wheel of the engine. Clutches of this type are shown in *Figs.* 151 and 152, the working sur-

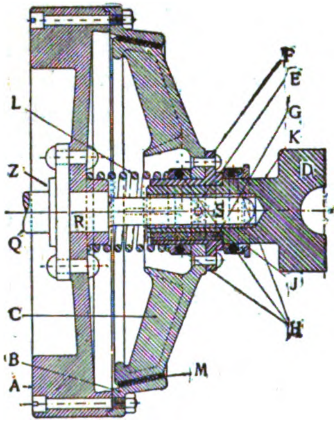

FIG. 151.

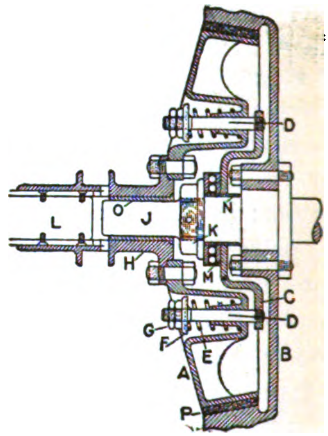

FIG. 152.

FIG. 151.—INTERNAL CONE CLUTCH OF THE PEERLESS CAR.

A, engine fly-wheel; B, female cone; C, male cone; D, universal coupling on male cone; E, bushing on D; F, collar keyed on D; G, key; H, ball bearings for taking up the thrust on disengaging clutch; J, flange on ball cone; K, receptacle on D for operating yoke; L, spiral spring for retaining clutch surface contact; M, leather band riveted on C, giving good friction surface; Q, main shaft; R, portion of shaft turned down to fit fly-wheel; S, portion of shaft turned down to receive clutch sleeve; Z, flange to which fly-wheel is bolted.

FIG. 152.—EXTERNAL CONE CLUTCH OF THE POPE-TOLEDO CAR.

A, fly-wheel clutch cone; B, fly-wheel; C, fly-wheel clutch stud plate; D, D, clutch spring studs; E, clutch spring; F, spring retainer; G, retainer lock nut; H, sliding sleeve for setting clutch; J, crank shaft end; K, crank shaft nut; L, tail shaft; M, ball thrust collar; N, ball thrust bush; O, sliding sleeve bush; P, clutch cone leather.

(Paragraph 379)

faces being leather-faced. An advance on this type is found in metal to metal contacts with either coil clutches, or cones with multiple discs not unlike the Weston triplex pulley blocks.

The most commonly employed change-speed gear consists of toothed wheels, a series of spur wheels, of different diameters, on a sliding sleeve being successively moved along the shaft to

mesh with wheels of another series mounted on the driven shaft. A well-known type of transmission, as shown in the accompanying section, *Fig.* 153, consists essentially of two parallel shafts. Of these, the countershaft carries four-keyed spur-wheels, D, E, F, G, the largest of which, D, is constantly in mesh, with pinion, A, on the clutch shaft. The clutch shaft, however, terminates with this constantly-meshed wheel, being bored longitudinally, so as to afford a bearing at L, for one end

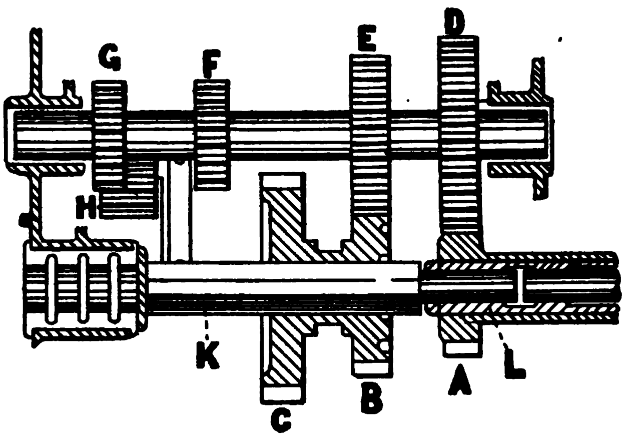

FIG. 153.—DIAGRAM OF THE DECAUVILLE TRANSMISSION GEAR.
A, is the spur pinion at the end of the clutch shaft; B and C, spurs on the sliding sleeve; D, E, F, G, spurs keyed to the second motion shaft; H, the reverse pinion, constantly in mesh with G, and giving the reverse when in mesh with C also; K, the square portion of the drive shaft; L, portion of same journaled into the clutch shaft.
(Paragraph 379)

of a second shaft, K, arranged continuous with it, but turning separately. The entire length of this second shaft, between bearings, is of square section, so that the double-faced gear wheel B C, may be slid from end to end by means of a fork set at one end of the gear-shifting lever.

When the double wheel is moved to the left, so that the pinion, F, on the countershaft meshes with the larger of the

two, C, on the square shaft, the low speed forward is obtained. By sliding the sleeve to the right, so as to bring the larger wheel, E, on the countershaft into mesh with the smaller one, B, on the square shaft, the second speed is obtained. By sliding the sleeve all the way to the right, so that, by a form of claw clutch its right-hand gear, B, grips the pinion, A, on the clutch shaft, the highest forward speed is obtained, the drive being then con-

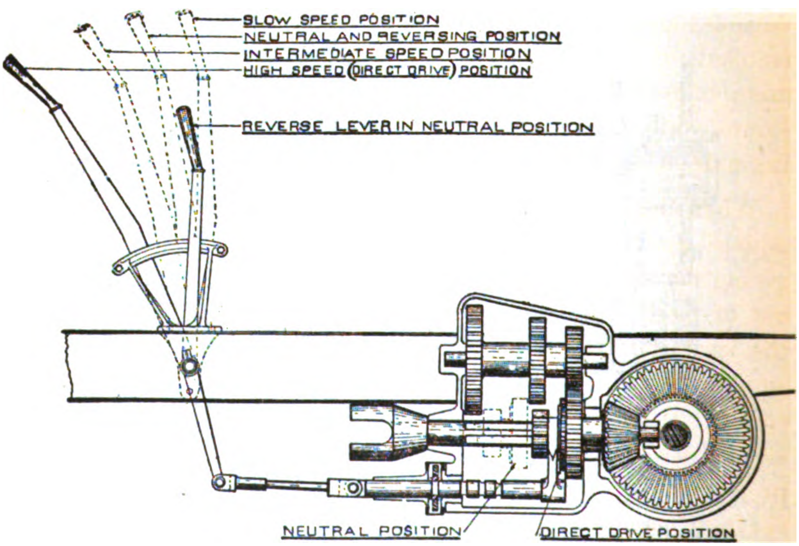

FIG. 154.—DIAGRAM OF CONTROL LEVERS AND TRANSMISSION OF THE PACKARD CAR. (Paragraph 879)

tinuous from the motor to the road wheels: this last constitutes what is known as a *direct drive.* The reverse is obtained when the sliding sleeve double wheels are moved all the way to the left so that the larger of the two, C, meshes with an idler pinion, H, constantly driven from the end gear, G, of the countershaft, by which means the rotation of the square shaft and of the road wheels is reversed.

Another popular form of change-speed or transmission gear is the "Sun and Planet" or epicyclic change gear. In this several small pinions rotate around a larger spur-wheel with which they are continually in mesh. The use of this type of gear is increasing.

A sectional elevation of a sliding change-speed gear is given in *Fig.* 154, showing the different lever positions required for various movements. It will be noticed, in this case, that power is transmitted from the motor, through the clutch, to the transmission gear by means of a shaft connected with universal joints, while the gear itself is close up against the rear or driving axle, which is rotated by means of bevel wheels.

When the lever is farthest forward, the small pinion on the square shaft is in gear with the largest on the countershaft, giving the slowest speed; the next step throws the forward gear out of mesh into a neutral position; another backward pull of the lever engages the larger wheel on the square shaft with the smaller wheel on the countershaft, giving an intermediate speed. Direct drive for top speed is effected by using the sliding wheels as a jaw-clutch, as illustrated, causing its teeth or projections to engage with other projections upon the short shaft to which the bevel pinion is keyed. Reversal is effected by placing the forward lever in the neutral position and then bringing an idle pinion, not shown, into mesh with the small wheel on the square driving shaft and the large one on the top or counter shaft; this is performed by means of the reverse lever operating a bell-crank. It will be noticed that the two gear wheels to the right are constantly in mesh with each other.

There are three chief methods of power transmission in general use: 1, the *parallel drive,* in which the motor shaft, countershaft and driving axle are parallel to each other, the motion

being transmitted directly through spur gearing or by means of chains; 2, the *Panhard* or *Continental drive,* in which the motor, whose shaft is longitudinal to the car, drives through a clutch to the change-speed gearing, and thence by bevel wheels to a sprocket countershaft, which by means of two side chains applies power to the rear wheels; 3, the *longitudinal shaft drive,* where the engine and change-speed gear are arranged as in the Panhard, but the bevel gearing is situated on the rear driving axle, the transmission being effected by a longitudinal shaft with universal joints at either end; this latter method is often termed the *propeller shaft drive.*

Many early cars were belt driven, but, owing to their being much affected by changes in the weather, the use of belts has been practically abandoned.

The wheels of a motor car are usually of the "artillery" pattern, that is, shaped like those of gun-carriages, the spokes all wedging together at the nave or hub. Except in very heavy cars, some form of rubber tire is universally fitted to the wheels; commercial vehicles having solid tires or else those of the cushion type, which has a thick tubular section; while pneumatic tires, pumped up to a pressure of from 75 to 100 lbs. per sq. in., are supplied to most passenger automobiles. To avoid side-slip or *skidding,* metallic studs or corrugations are often fitted to the pneumatic tires, while steel chains and leather bandages are frequently furnished for the same purpose.

The axles of an automobile are generally *dead,* that is prevented from rotation, the wheels revolving freely on their tapered ends; where the shaft drive is employed, however, a *live* rear axle is fitted, it being driven by a bevel gearing at its middle portion. In such a drive it is necessary to have a differential arrangement so that the outer wheel may revolve faster than the inner when rounding a curve.

The short axle-ends of the front wheels are hinged on the forward axle; these two pieces are connected together by a system of linkage, which provides for steering the car by slewing the front or steering wheels towards either hand. The movement of the steering gear is effected by a large hand wheel.

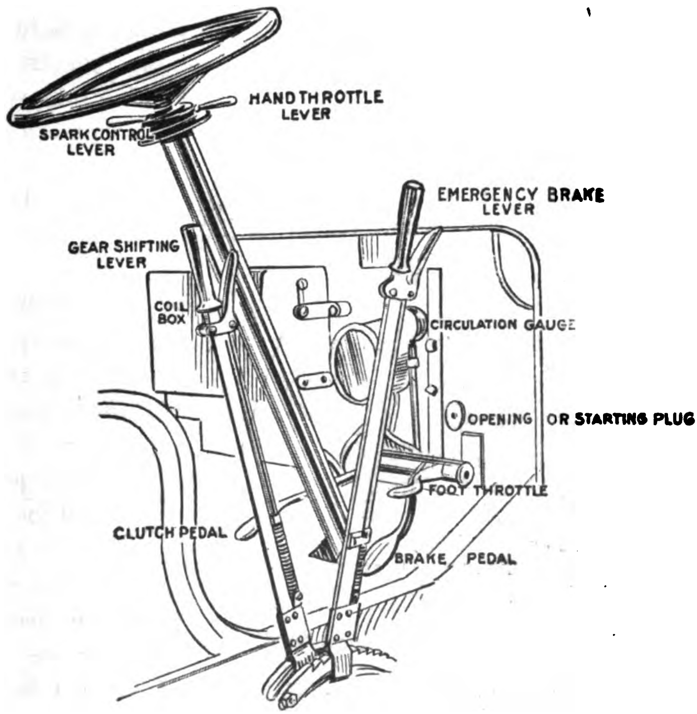

FIG. 155.—CONTROL LEVERS AND APPLIANCES OF A MOTOR CAR (Paragraph 879)

Brakes are usually of a band or constricting type acting upon drums or pulleys on the driving axle, or work on the expansion principle, shoes being thrust outwards against the inner circumference of a cone or flanged disc. A plain band brake is

ineffective on a motor car as it will not act should the car begin to run backwards on a steep gradient; it is necessary to use two shoes, one on either side of the drum, or to have each end of the brake band attached to an arm upon the lever rock-shaft, thus applying the braking force in either direction.

A study of the illustrations given in *Figs.* 148 and 149, will show the arrangement and appearance of the parts just enumerated, and also the manner in which the controlling devices are located in convenient positions.

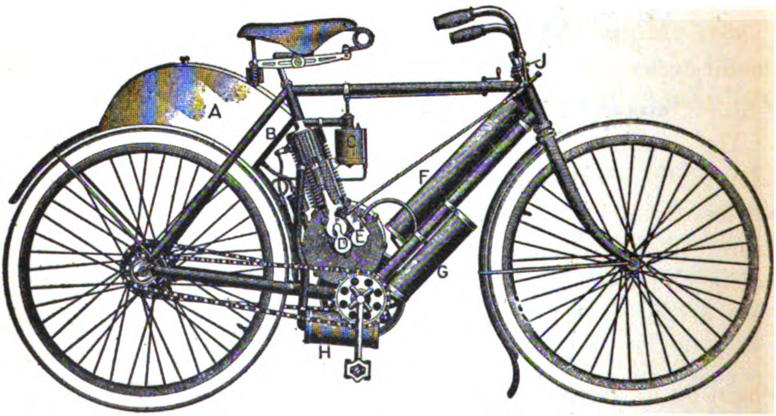

FIG. 156.—AMERICAN MOTOR BICYCLE.

A.—Gasoline Tank.
B.—Lubricating Oil Tank.
C.—Carburetter.
D.—Valve Gear Case.
E.—Primary Circuit Breaker.
F.—Battery.
G.—Induction Coil.
H.—Exhaust Muffler.
J.—Grip Control Lever.

(Paragraph 380)

The spark control and throttling levers are carried on the steering-wheel, an extra throttling device being afforded by a pedal, it being possible by these means, to vary the speed of the motor illustrated from 300 to 1,300 revolutions per minute. The friction clutch may be thrown out of gear, when desired, by means of the pedal shown in the elevation view, while a third pedal applies the brakes. The two vertical levers shown,

control, respectively, the emergency brake, and the change-speed gear; the inner lever, which actuates the latter being moved into one or another of the recesses in the quadrant according to the rate of speed desired.

The sight feed lubricator, gauges, spark coil and other details are attached to the dashboard immediately in front of the driver's seat, as will be better seen in *Fig.* 155, which illustrates the neat arrangement of the controlling levers, etc., on a good-class car.

380. **Motor-Cycles.** Reference has already been made to motor-cycles; a representative motor bicycle is illustrated in *Fig.* 156.

The framing is but little different from that of an ordinary bicycle, the air-cooled motor being slung within the frame; this varies usually from 1¾ to 2½ horse-power, but expert riders, more especially in hilly country, use motors of 3½ to 5 horse-power or more. The weight of a 2½ h. p. machine is 75 to 80 lbs., a 6 h. p. cycle weighing 160 lbs.

The model illustrated drives through gearing and a sprocket-chain on to the rear wheel; in this case, braking can generally be effected only by the compression within the cylinder. A better and more general method is the direct drive from the motor shaft by means of a leather or raw-hide belt on to a separate rim upon the driving wheel; an effective foot brake is fitted which is applied to this rim.

It is scarcely necessary to add that the bicycle is of the free wheel type; the rider uses the pedals in starting or in ascending a steep hill, but not at other times.

The various levers for regulating the fuel supply, for controlling the spark, for throttling, or for lifting the exhaust valve

at starting, are all disposed conveniently around near the handle-bars. A rim brake is frequently fitted, bearing on the inside of the rim of the front wheel. Thin tanks are conveniently disposed behind the rider, or between his legs, containing the supplies of fuel and lubricating oil; the gasoline feeds into the carburetter by gravity.

Jump spark ignition is almost exclusively used, and the higher-powered machines are fitted with high tension magnetos.

Six to eight horse-power motors, with two, three, or even four cylinders are employed with tri-cars and quadricycles, but they are generally water cooled and a change speed gear is employed.

The motor bicycle is generally sufficiently powerful to carry a heavier load than its rider, the accommodation for an extra passenger being attached in various ways, either on a seat, supported by one wheel, which is secured abreast of the rider, or in a two-wheeled seat which replaces the front wheel.

This last constitutes the general design of the *tri-car* previously referred to.

The great difficulty of the motor cycle is vibration; this is sought to be nullified by larger saddles with coiled-spring supports or spring pillars; also by double forks to the handle-bars, saving jar to the wrists, and the like.

The general tendency is to build motor cycles without pedals, this being more apparent in the tri-cars and quads, which latter approximate usually to small motor-cars.

CHAPTER XXVII.

USEFUL RULES AND TABLES.

381. Weight of Coal and Coke in Pounds per Cubic Foot:—

In addition to the Rules and Tables given in the body of this work, the following are introduced herein for convenient reference (see Index):

Anthracite Coal, market sizes, loose................52-56;
" market sizes, moderately shaken....56-60;
" market sizes, heaped bushel, loose..77-83;
Bituminous Coal, broken, loose....................47-52;
" moderately shaken................51-56;
" heaped bushel..................70-78;
Dry Coke 23-32;
" heaped bushel (average 38).............35-42.

Standard Bushel, American Gas Light Association: 18½ inches diameter, and 8 inches deep = 2150.42 cubic inches.

A heaped bushel is the same plus a cone 19½ inches diameter and 6 inches high, or a total of 2747.7 cubic inches.

An ordinary heaped bushel = 1¼ struck bushels = 2688. cubic inches = 10 gallons dry measure.

Crude Petroleum = 7.3 pounds per U. S. gallon.

382. Melting Points of Metals:—

	Centigrade	Fahrenheit
Sulphur	115°	239°
Tin	230	446
Lead	326	618
Zinc	415	779
Aluminum	625	1157
Silver	945	1733

Gold	1045	1913
Copper	1054	1929
Cast Iron, white.......	1135	2075
" gray	1220	2228
Steel, hard	1410	2570
" mild	1475	2687
Palladium	1500	2732
Platinum	1775	3227

383. **Heat Units:—**

A French Calorie = 1 Kilogram of H_2O heated 1° C., at or near 4° C.

A British Thermal Unit (B. T. U.) = 1 pound of H_2O heated 1° Fahr., at or near 39° Fahr.

A Pound-Calorie Unit = 1 pound of H_2O heated 1° C., at or near 4° C.

1 French Calorie = 3.968 B. T. U. = 2.2046 Pound Calories.

1 British Thermal Unit = .252 French Calories = .555 Pound Calories.

1 Pound-Calorie = 1.8 B. T. U. = .45 French Calories.

1 B. T. U. = 778 foot-pounds = Joule's mechanical equivalent of heat.

1 Horse-power (H. P.) = 33,000 foot-pounds per minute.

1 Horse-power $= \frac{33,000}{778} =$ 42.42 B. T. U. per minute.

1 Horse-power = 42.42 × 60 = 2545 B. T. U. per hour.

384. **Calculation of Diameters of Pipe.** In using the following formula, ample allowance should be made for the effect of temperature.

Where **d** = diameter of pipe in inches; **Q** = quantity of gas in cubic feet per hour; **l** = length of pipe in yards; **s** = specific gravity of gas, air being 1; **h** = head or pressure in inches of water.

$$d = \sqrt[5]{\frac{Q^2\, s\, l}{(1350)^2\, h}}$$

The volume of a gas varies as its absolute temperature, which is the ordinary temperature + 273° C. or + 461° Fahr. See Paragraph 13.

385. Equivalent Heating Values for Gas, Fuel Oil, and Coal. Equivalent values for natural gas and coal vary considerably on account of variations in their quality, and differences in practice, but approximately—

35,000 cubic feet of natural gas = in heating value, 1 ton of coal, and—

1 pound of fuel oil = 1.45 pounds of coal.

386. Conversion of English into Metric Weights and Measures may readily be made by the use of the following Constants—

Length: 1 inch = 0.0254 meter.
1 foot = 12 inches = 0.3048 meter.
3.281 feet = 39.37 inches = 1 meter.

Volume: 1 U. S. gallon = 0.16057 cubic foot = 4.537 liters.
1 cubic foot = 0.02832 cubic meters = 2.83 liters.
35.32 cu. ft. = 220 U. S. gals. = 1 cu. meter = 1000 liters.

Weight: 1 lb. = 16 ozs. = 7000 grains = 0.4536 kilogram.
2.2046 lbs. = 1 kilog. = 1 liter of water at 4° C.
0.9842 ton = 1 ton = 1000 kilogrammes (kilos).

Pressure: 1 lb. per sq. in. = 0.0703 kilog. per sq. cm.
1 atmosphere = 14.7 lbs. per sq. in. = 1.0333 kilog per sq. cm.
14.223 lbs. per sq. in. = 1 kilog. per sq. cm.

Work: 1 foot-pound = 0.13825 kilogrammeter.
7.233 ft. lbs. = 1 kilogrammeter.

Power: 1 horse-power = 1.01385 force de cheval.
0.9863 H. P. = 1 force de cheval = 75 kilogrammeters per second.
1 watt = 0.00134 H. P. = 0.1019 kilogrammeter per second.

387. **Rules for Calculating Power Required.** To compute the horse-power required to raise a given quantity of water to a certain height, multiply the gallons per minute by 8.35, and multiply this product by the height in feet; the result will be the power required in foot-pounds. To reduce this to horse-power per minute divide by 33,000. Usually, an allowance of 50 per cent. is made for friction and other loss.

To estimate the horse-power required to deliver an electric load, multiply the amperes by the voltage, the product will be the total number of watts. An electrical horse-power is 746 watts, therefore, divide the total number of watts by 746 and the result will be the electrical horse-power. To ascertain the brake horse-power of the engine when direct connected to generator, multiply the amperes by the voltage and divide by 660; the result will be the approximate brake horse-power of the engine.

If the engine is of the belted type, divide the total number of watts by 550 instead of 660.

In computing the horse-power it is customary to allow ten 16 candle-power lights to the horse-power. A 16-candle-power light is equal to 55 watts.

388. Rules for Determining the Size and Speed of Pulleys and Gears. The pulley from which the belt runs is usually called the *driver,* and the one which it rotates is called the *driven.*

If the size of toothed wheels be required, the number of teeth must be used in the place of the diameter wherever the latter occurs in these rules.

To find the diameter of the driver, when the diameter of the driven and its revolutions, and also the revolutions of the driver are given; multiply the diameter of the driven by its revolutions and divide the product by the revolutions of the driver.

To find the diameter of the driven, when the revolutions of the driven, and the diameter and revolutions of the driver are given; multiply the diameter of the driver by its revolutions and divide the product by the revolutions of the driven.

To find the revolutions of the driver, when the diameter and revolutions of the driven, and the diameter of the driver are given; multiply the diameter of the driven by its revolutions and divide the product by the diameter of the driver.

To find the revolutions of the driven, when the diameter and revolutions of the driver, and the diameter of the driven are given; multiply the diameter of the driver by its revolutions and divide the product by the diameter of the driven.

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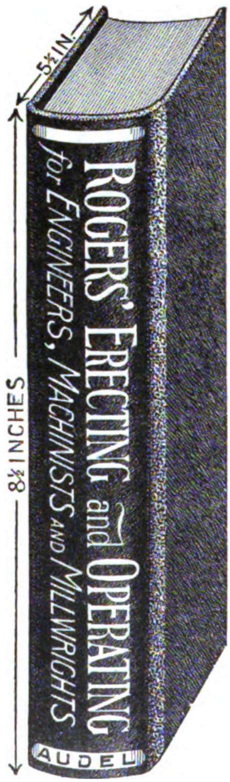

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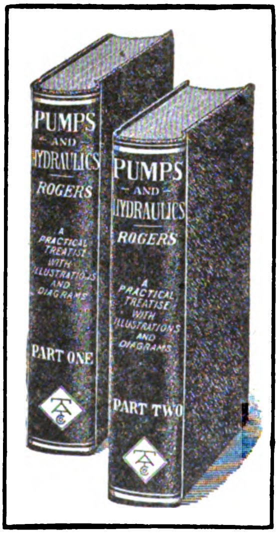

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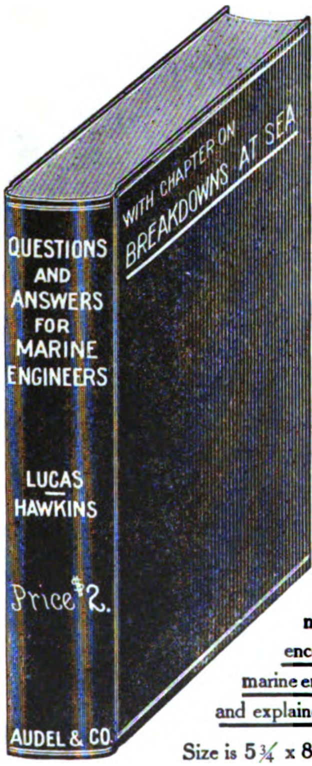

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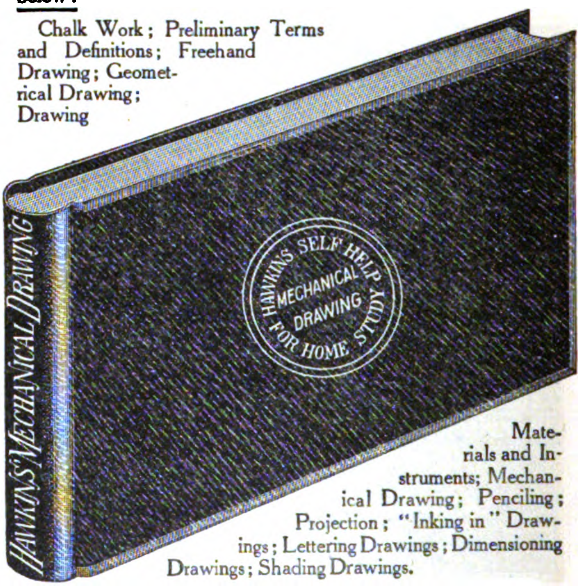

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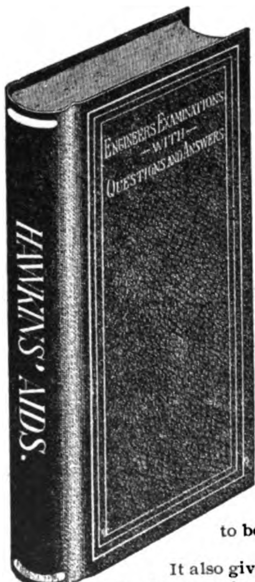

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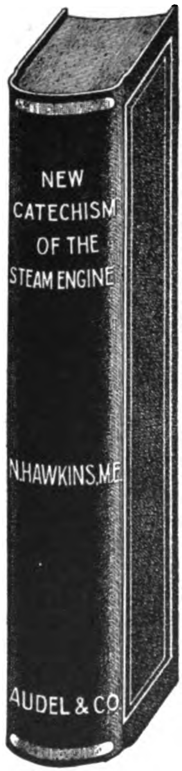

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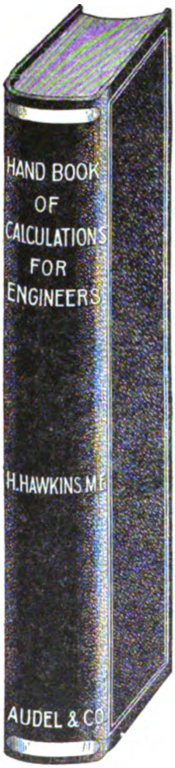

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